Innovation and Coordination for ICT Standards : the Role of Essential Patents

Justus Baron

École doctorale n° 396 : Economie, Organisation, Société

Doctorat ParisTech

THÈSE

pour obtenir le grade de docteur délivré par

l'École nationale supérieure des mines de Paris

Spécialité " Economie et finance "

présentée et soutenue publiquement par

Justus Alexander BARON

le 24 septembre 2012

Innovation et coordination dans les standards NTIC - le rôle des brevets essentiels

Directeur de thèse : **François LEVEQUE**
Co-encadrement de la thèse : **Yann MENIERE**

Jury

Prof. Dr. Marc Bourreau, Professor of Economics, Telecom ParisTech	Président
Prof. Dr. Knut Blind, Professor of Economics, Technische Universität Berlin	Rapporteur
Prof. Timothy Simcoe, Associate Professor of Strategy and Innovation, Boston University School of Management	Rapporteur
Dr. Yann Ménière, Assistant Professor of Economics, Cerna, Mines ParisTech	Examinateur
Prof. Dr. François Lévêque, Professor of Economics, Cerna, Mines ParisTech	Directeur de thèse

T H È S E

MINES ParisTech
Cerna
60 Boulevard Saint Michel 75272 Paris Cédex 06

Acknowledgements

I thank my supervisor François Lévêque, who has made this Ph.D. thesis possible and has directed my research on a fascinating track. Furthermore, I wish to thank Knut Blind and Reiko Aoki, who have welcomed me in their respective departments and have often assisted me through their helpful advice. I thank Henry Delcamp and Tim Pohlmann for three years of joint work and friendship. Without their company in the sometimes cumbersome and late hours of work, I would have had much less fun in writing this thesis than I had. I am heavily indebted to Yann Ménière for his always insightful advice (not only on the economics of standardization), for his constant availability and commitment, and for transmitting some of his curiosity and enthusiasm for research.

I look back to a great time at Cerna, TU Berlin and Hitotsubashi University. I thank my colleagues, and especially Florian Berger, Michel Berthélemy, Alexander Cuntz, Arnaud de la Tour, Jan Eilhard, Stephan Gauch, Kerstin Goluchowicz, Gabrielle Moineville, Lina Rangel, Paula Restrepo, Julius Rauber and Paul Wakke for all the good memories. I would also like to thank Mathieu Glachant for the lively discussions and for his work to make the Cerna a good place to study and work. I especially thank Sésaria Ferreira for having been there whenever something went wrong.

Finally, I would also like to thank my family, Luciana, and my friends (especially Sami and Lidia) for helping me through the inevitable periods of doubts during these three years of research and for reminding me of all the other things that matter beside standards and patents.

Preface

The first chapter, *The Private and Social Value of Patents in Discrete and Cumulative Innovation*, is coauthored on an equal basis with Henry Delcamp (Mines ParisTech). This article has been presented at the EPO/OECD Conference on Patent Statistics for Decision Makers, Vienna, November 2010, and was published in Scientometrics, Volume 90(2), 2012.

The second chapter, *The Strategies of Patent Introduction into Patent Pools*, is coauthored on an equal basis with Henry Delcamp (Mines ParisTech). This article has been presented at the Schumpeter Conference, Aalborg, June 2010, the European Research Academy on Standardization Conference, Lausanne, June 2010, the European Policy for Intellectual Property Conference, Maastricht, September 2010, the European Association for Research in Industrial Economics Conference, Istanbul, September 2010, and the Asia-Pacific Innovation Conference, Singapore, November 2011. The article is currently under revision for publication in the Oxford Economic Papers.

The third chapter, *Patent Pools and Patenting for Technological Standards*, is coauthored on an equal basis with Tim Pohlmann (TU Berlin). This article was presented at the 4th INTERTIC Conference on Competition in High Tech Markets, Innovation, Networks and Multi-sided Markets, Milan, October 2010, at the Conference ICT and Economic Growth, Strategy in ICT Markets, Munich, November 2010 and at the 4th ZEW Conference on the Economics of Innovation and Patenting, Mannheim, May 2011. I also presented the findings of this research in invited speeches at Hitotsubashi University, Tokyo, and Hokkaido University, Sapporo.

The fourth chapter, *Joint Innovation in ICT Standards: How Consortia Drive the Volume of Patent Filings*, is coauthored with Yann Ménière (Mines ParisTech) and Tim Pohlmann (TU Berlin), whereby I carried through together with Tim Pohlmann the empirical analysis. The article was presented at the 2nd Asia Pacific Innovation Conference, Singapore, November 2011, the 7th International Conference on Standardization and Innovation in Information Technology SIIT, Berlin September 2011, the Telecom ParisTech Conference on the Economics of ICT, Paris, September 2011, the 6th Annual Conference of the EPIP Association: Fine-Tuning IPR debates, Brussels, September 2011, the RIETI Workshop on Standards and Innovation, Tokyo, April 2012, and at the ICTNET 4th workshop – ICT, R&D, Intangibles and ICT Diffusion, London, April 2012.

The fifth chapter, *Essential Patents and Standard Dynamics*, was coauthored with Tim Pohlmann (TU Berlin) and Knut Blind (TU Berlin), whereby I function as corresponding author. I presented this paper at the 7th International Conference on Standardization and Innovation in Information Technologies, Berlin, September 2011, the Telecom ParisTech Conference on the Economics of Information and Communication Technologies, Paris, September 2011, the European Policy for Intellectual Property Conference, Brussels, September 2011, the 5th INTERTIC Conference on Innovation and Competition, Venice, November 2011, the RIETI Workshop on Standards and Innovation, Tokyo, April 2012, the Telecom Ecole de Management Conference on Innovation in ICT, Paris, June 2012 and at the 10th ZEW Conference on the Economics of Information and Communication Technologies, Mannheim, June 2012. This chapter is my job market paper.

Résumé

Cette thèse étudie l'innovation et la coordination dans les standards des Nouvelles Technologies d'Information et de Communication (NTIC). Dans cinq contributions économétriques, j'analyse le rôle des brevets essentiels. Les brevets essentiels sont des brevets qui protègent des inventions indispensables à toute mise en application d'un standard technologique. Le nombre croissant de ces brevets essentiels nourrit l'inquiétude que l'innovation dans les NTIC puisse être étouffée dans un véritable buisson de brevets. Les firmes actives dans la standardisation ont réagi à ce défi en créant des mécanismes innovateurs de coordination, et notamment des consortia informels de standardisation et des pools de brevets.

La compréhension des mécanismes et incitations liés aux brevets essentiels se heurte actuellement à un manque d'études empiriques. Je contribue à la recherche économique à travers la construction d'une large base de données sur les brevets et les standards, des avancées méthodologiques dans l'analyse scientométrique ainsi qu'une analyse économétrique fondée dans la littérature théorique actuelle. La thèse est organisée selon trois axes de recherche, qui explorent respectivement les caractéristiques des brevets essentiels, le nombre de brevets déposés autour des standards, ainsi que des mesures du progrès technologique des standards.

Mes recherches mettent en lumière le caractère spécifique des brevets essentiels. En particulier, je montre que parmi les brevets essentiels, les brevets qui protègent des inventions plus significatives n'ont pas plus de valeur pour leurs propriétaires. Cette particularité des brevets essentiels incite à des stratégies opportunistes, notamment la multiplication des dépôts de brevets essentiels incrémentaux et étroits. Les pools de brevets peuvent contribuer encore davantage à cette inflation de brevets, et permettent notamment à leurs membres fondateurs d'introduire un grand nombre de brevets peu significatifs, mais très ciblés sur le standard.

Les pools de brevets incitent par ailleurs à augmenter le nombre de brevets déposés autour des standards technologiques. Dans le cas de pools dont la création a été attendue, cet effet a lieu dans les années qui précèdent le lancement du pool. Les consortia informels associés à la standardisation ont également des effets sur le nombre de brevets déposés autour des standards. Dans le cas de standards caractérisés par un niveau insuffisant d'investissements en R&D spécifique, les consortia induisent une augmentation du nombre de dépôts de

brevets. Dans le cas de standards pour lesquels un niveau excessif de redevances pour les brevets essentiels induit des courses aux brevets, les consortia informels peuvent réduire le nombre de brevets déposés.

J'étudie également l'effet des brevets essentiels sur le progrès technologique des standards. Je montre que l'inclusion de technologies brevetées dans un standard augmente le taux de mises à jour du standard, mais réduit le risque de remplacement. J'en déduis que les brevets essentiels induisent les organismes de standardisation à substituer le progrès technologique continu au progrès discontinu. Cependant, le taux plus élevé de mises à jour n'est pas suffisant pour expliquer l'augmentation de l'espérance de vie des standards. Les brevets essentiels donc réduisent le taux de remplacement de standards également à travers d'autres mécanismes, notamment à travers des blocages institutionnels et des conflits d'intérêts.

Table of Contents

Introduction

1. Context:

In April 2011, Apple and Samsung started a huge legal battle over patent infringement in mobile communication. Currently, these two companies alone are opposed in 19 ongoing lawsuits in 12 different courts. This clash is however just one episode in a series of litigations and antitrust investigations regarding the licensing of standard-essential patents. Essential patents are property rights on technology that is necessary for any implementation of a technological standard. Recent generations of standards in Information and Communication Technologies (ICT) incorporate an increasing number of such essential patents. The interplay between patents and standards is thus increasingly important, but also increasingly problematic. While the objective of standardization is to foster the dissemination of new technology, the function of the patent system is to grant an innovator the temporary right to exclude others from any use of an invention. As several recent important technology standards incorporate hundreds or even thousands of essential patents held by dozens of different firms, there is a risk that the development and spread of innovative ICT standards is jeopardized by legal disputes between holders of mutually blocking patents. In response to these disputes, standardizing firms have developed new institutions and mechanisms to reconcile the conflicting objectives of standardization and the patent system. The most important of these mechanisms are patent pools, licensing out bundles of essential patents owned by different firms, and informal consortia, coordinating the contribution of proprietary technologies by rivaling firms in the process of developing new standards.

The regulatory challenges and the original mechanisms emerging around patented technologies in standards have triggered much attention both by practitioners and economic researchers. Economic analysis has guided important regulatory decisions at the interface between patents and standards, such as the adoption of a permissive stance with respect to patent pools and an increased recognition of the role of informal standards consortia. In particular competition authorities have redefined their policy, striking a new balance between their traditional suspicions against coordination among competitors and the risk that single holders of essential patents abuse of their dominant position. Nevertheless, these important decisions are so far insufficiently grounded in solid empirical evidence. The economic research has left many important empirical questions unanswered: how do patent pools affect the incentives to innovate and file essential patents? Do consortia contribute to increase efficiency in the development of proprietary technology for standards? What is the effect of essential patens on the technological progress of standards?

My Ph.D. thesis addresses this gap in the economic literature and provides empirical answers to the aforementioned questions. I build up large databases of standards, consortia, patent pools, essential patents and standard-related patent files. I assess various methodologies to match standards with patents, and I evaluate the use of different quantitative patent and standard characteristics as indicators for economic research. Based upon these methodological advances, I carry out a sophisticated econometric analysis grounded in recent economic theory. I find empirical evidence for a particularity of essential patents: within the sample of essential patents, patents protecting more important inventions are not more valuable for their owners. This characteristic of essential patents induces incentives to file numerous narrow and relatively insignificant patents on standard-essential technology. I furthermore show that on the one hand patent pools increase the incentives to file and declare essential patents, and I provide evidence for opportunistic strategies of patent introduction into patent pools. Informal consortia on the other hand can increase the efficiency of patenting with respect to standardization: consortia have a positive effect upon the number of patent files in situations where R&D incentives are insufficient, and a lower positive or even a negative effect in situations of excessive patenting. Analyzing the effect of essential patents on the technological progress of standards, I find that patents induce a more continuous progress of standards, increasing the number of incremental upgrades and reducing the rate of discontinuous standard replacements.

My research goes beyond the imminent policy debate on the regulatory framework for ICT standardization. I also contribute to the economic literature on innovation and standardization through an original analysis of the role of standards and essential patents. I describe standardization as a continuous selection mechanism, streamlining the distributed R&D efforts of numerous actors towards the frontier of cumulative technological progress. Essential patents are an original appropriation mechanism specially tailored to this distributed innovation. Rather than exclusive property rights on units of technology, essential patents are a right to partake in the control over a jointly developed technology. Essential patents function as bargaining chips, allowing for coordination and contracting among the various firms participating in the joint development of technological standards.

2. Innovation and standardization:

Standards establish interoperability between technologies in a network of users. Interoperability results from a selection process: network participants can interoperate when they agree on a common, *standard* technology. Such a common standard can emerge as dominant design or *de facto standard* from uncoordinated adoption decisions, when each adopter decides individually to adopt a technology, but takes the adoption choices of other users into account. In other cases, the users explicitly agree on a *de jure standard* (David and Greenstein, 1990; Farrell and Simcoe, 2011). In both cases, the function of standardization is to select one technological solution among a possibly broad set of options for the sake of variety reduction (Tassey, 2000).

The selection is often a matter of discretionary choice: ex ante, there are few objective criteria for choosing the exact width and length of a paper format, the optimal disposition of letters on a keyboard, or the side of the road on which vehicles have to drive. Nevertheless, once a standard has emerged, users of the standard incur complementary sunk investments which are specific to the selected format, and the standard becomes increasingly costly to replace. Standardization is thus a crucial event in the history of a technology: through standardization, one specific way of doing things gets chosen as a stable basis for the future technological progress, while alternative technologies, many of which ex ante equivalent or even superior to the elected standard, are almost irreversibly abandoned (Arthur, 1989).

This mechanism can be illustrated by an example from telecommunication standardization: multiple access to a single channel such as a phone line or frequency bandwidth can be governed by splitting access time into different time intervals (TDMA), by assigning each communication a precise frequency range (FDMA), or by spreading the signals of each communication over a spectrum, identified by a code signal (CDMA). Each of these options can be developed into a viable telecommunication technology. Inside a common network, it is however necessary that all users abide by the same multiple access technology. Interoperability and communication without interference thus require the selection of a single technology for each communication channel. This is precisely the role of standardization.

The development of a modern telecommunication standard is a long series of many, increasingly incremental technological choices. Once CDMA was selected as technological option, standard setters had to agree upon the details of the coding and decoding technology and many other features in order to develop a particular standard such as CDMA2000. This standard is in turn an integral component of a yet more complex system such as UMTS. Standardization thus eliminates variety on one technological level, after which a variety of technological options is developed to address related technological problems on a more incremental level, until once again standardization eliminates variety and the focus of technological progress moves further on.

There are however crucial differences between a complex technology standard and our earlier examples of simple standards. While no particular science or technique is required to drive on the right side of the road, coding speech data in certain syntax or transmitting signals in a determined frequency range requires specific technology. It is not enough to agree upon a particular technological option, these options have to be developed in costly R&D. The firms, universities or individuals developing these options can patent their inventions, and use these patents to recoup their costs. If the patent covers a technology which is selected as standard component, it becomes a valuable essential patent with blocking power over any adoption of the standard. If another option is selected for the same functionality, the patent is practically worthless. Another crucial difference is that technological standards need to respond to an advancing state of the art. Driving on the right side of the road works equally well for horse carriages and modern cars. In case of telecommunication standards, different coding or signal transmission technologies are needed for transmitting speech signal or huge data loads such as video streaming over mobile internet connection. Furthermore, scientific and technological progress can open up technological opportunities which were unforeseen at the moment of standardization. Technology standards need to respond to technological change, and in spite of the numerous costs of standard replacement, this response often implies reversing prior technological choices.

My thesis focuses on this interplay between the development of new technologies and their adoption as technological standard. In my analysis, standardization is a central aspect of innovation. Through the selection of a specific technological solution, standards set a solid basis for the next step in a cumulative technological progress (Blind, 2004 pp.186-218). The features of this selection process are taken into account by those who develop the variety of technological options: indeed, R&D in cumulative technologies is targeted at problems of existing systems, and innovators aim at selection of their technologies as part of a standard. Standardization is thus not only a selection between existing technological options: the expected outcome of standardization implicitly or explicitly specifies the requirements for future technology, and streamlines R&D investments towards specific problems of an existing technological system. Standardization thus plays a role in coordinating continuous, cumulative technological progress.

But standardization is not less important in the coordination of disruptive technological progress. In order to replace an installed technological system, innovators need to develop a fully viable alternative complex system. This implies streamlining R&D investment towards proposing solutions for specific technical problems of a technology which is not currently used. Such coordination on discontinuous change can only be successful if a large number of innovators can agree on the basic features of the future technology, commit to specific practices, and contract on the assignment of different tasks.

3. Coordination around technological standards and the role of patents

The technological progress of standards requires a coordinated cumulative R&D effort. In many cases a single company can coordinate this effort: many standards have been developed by single large firms, who can use patents to gain the exclusionary control over a proprietary standard. With strong property rights, single firms can also coordinate the technological progress through distributed innovation: as a platform leader for a standard technology, a firm can for instance contract targeted R&D investments from those who have specific technological capacities, and streamline the R&D of its suppliers and customers on a focal technology. De facto standards such as Apple's IOS and Microsoft's Windows evolve in such ecosystems coordinated by a strong leader (Gawer and Cusumano, 2002).

In other cases, especially in very complex systems involving large numbers of actors, various companies decide to join their capacities and technologies, share the risk and the cost, commit on adopting the future technology and thus guarantee the existence of a demand. This coordination requires a lot of communication, signaling, and strong commitments. Many important standards, such as the CD or DVD formats, have been developed by such informal coalitions of firms, called in the literature *ad hoc standards consortia*. Ad hoc coordination on new technological standards requires identifying potential partners, building trust and reputation, agreeing on a *modus governandi*, and detailed contracting on the respective investments and gains. Intellectual property rights are vital in this coordination process to allow contracting and credible commitment.

The building of a coalition and the construction of a viable contractual frame for the development of a new standard constitute sizeable sunk investment. Most of the important technological standards are therefore developed in institutionalized formal Standard Setting Organizations (SSO), providing a framework for the continuous development of new standards[1]. Represented in early models of standardization as ideal-typical social planners, these SSOs are in fact economic institutions, shaped by incentive structures and relations of power. Like in de facto standardization and ad hoc consortia, patents play an important role as coordination device among SSO members. Patent protection is an important incentive for developing standard-essential technology (Geradin, 2006), and it is an important condition for technology holders agreeing to contribute to standard development (Layne-Farrar et al., 2011). Nevertheless, patents can also exacerbate coordination failures and opportunistic strategies. Participants to standardization have engineered ad hoc solutions to address these problems, and over time, sophisticated mechanisms have emerged to coordinate corporate strategies with respect to patents in formal standardization. More recently, also these mechanisms exhibit symptoms of coordination failures, and there is an ongoing process of organizational innovation for addressing the coordination failures inside the coordination mechanisms.

The birth of the current institutional framework for formal standardization is intimately related to the liberalization of the international telecommunication industries, which can be dated back to the International Telecom Regulations in 1988[2]. Through this process of liberalization, formal standardization gradually emancipated from intergovernmental decision making, opening up the possibility for corporate participation and the inclusion of proprietary technology. In response to these new possibilities, a broad variety of SSOs and consortia have emerged, including nowadays dominant players such as ETSI and the IETF[3]. These new actors and their corporate standardization participants have contributed to an unprecedented technological evolution of ICT standards in the past twenty years, but also to a very large number of patents on components of formal standards.

The first important conflicts around patents on standard components emerged around the European 2G mobile phone standard GSM, when the cross licensing practices of Motorola allegedly drove large numbers of handset manufacturers out of the market (Bekkers et al., 2002). In response to these allegations, the newly founded ETSI (emanating from the

[1] Examples of SSOs include national organizations such as the American National Standards Institute (ANSI) or the French Autorité française pour la normalisation (AFNOR), regional bodies like the European Telecommunication Standardization Institute (ETSI), and worldwide SSOs such as the International Telecommunication Union (ITU).
[2] http://www.itu.int/osg/csd/wtpf/wtpf2009/documents/ITU_ITRs_88.pdf
[3] The Internet Engineering Task Force (IETF) is responsible for many of the most important internet standards

ad-hoc GSM consortium) adopted an IPR policy specifying the obligations to disclose essential patents, and to provide licenses on a fair, reasonable and non-discriminatory (FRAND) basis. This policy is nowadays practiced by almost all significant SSOs. The disclosure obligation and the notion of FRAND licensing terms constitute the basis for the emergence of essential patents as a specific legal institution with sui generis obligations and mechanisms.

Nevertheless, these notions initially lacked tangible content. This lack became apparent in two cases of alleged anti-competitive conduct: in 2006, Broadcom and eventually Nokia filed formal complaints to the European Commission against Qualcomm, arguing that the licensing conditions for Qualcomm's patents related to ETSI's 3G standards did not respect the company's FRAND commitment. In another widely cited case, in July 2007, the European Commission launched investigations against Rambus, which allegedly had failed to disclose its patents to the semiconductor standards consortia JEDEC[4]. Even though these cases did not result in clear-cut decisions from competition authorities, they triggered an important amount of legal and economic research, policy initiatives and practitioner discussions which considerably sharpened the notion and particular status of essential patents. In December 2010 the European Commission adopted new guidelines for the application of European Competition law to horizontal agreements, including standardization agreements[5]. These guidelines condition the presumption of pro-competitive effects of standardization upon disclosure policies and FRAND licensing terms. While the precise implications of the rules regarding essential patents are still open to a lively debate, this choice of the European Commission consecrates the notion of essential patent as regulatory principle for standardization of proprietary technology. More recently, the European Commission launched a new series of investigations into disputes regarding the licensing of essential patents, including the litigations between Apple and Samsung. The motivation for these investigations is the authorities' commitment to further define the content of the rules on disclosure of essential patents and FRAND licensing.

In parallel to this evolution, standardizing companies have come up with industry-driven mechanisms tailored to the problems of essential patents on standards. In 1997 and 1999, the coalitions including almost all the holders of essential patents on the DVD and MPEG2 standards created the first large contemporary patent pools. While many patent pool licensing schemes had existed until World War 2, strict antitrust enforcement had impeded the pooling of patents held by different companies since 1945. In order to overcome this

[4] Both the Rambus and the Qualcomm case also triggered antitrust investigations in the US, even though the focus of the European and US investigations differed significantly
[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2011:011:0001:0072:EN:PDF

resistance, the pool initiators proposed a list of safeguards, including non-discriminatory access to the pool for all holders of essential patents, third-party evaluation of the patent essentiality, FRAND licensing terms and the unrestricted possibility to license out all the included patents individually. The American and European competition authorities granted a favorable business review for these licensing schemes, reflecting their intention not to take action against the companies joining these pools. After this successful precedent, the organizational principles of the DVD and MPEG2 patent pools constituted a template for patent pools that do not run afoul of competition law, and since then around 50 patent pools following the same basic rules have been initiated for standardized technology.

While patent pools have contributed to the wide implementation of standards such as MPEG2 (licensed out to 1.421 firms), the experience of the last fifteen years has also revealed the pitfalls of the current pool design. For instance, the failure of several important patent pools, most noticeably for the 3rd generation of mobile phone standards, demonstrates the difficulties to build up comprehensive coalitions of patent holders for creating a pool. Pools seem to find it particularly difficult to attract the holders of most valuable patents, who fear that their share in the royalty revenue is unduly diminished through opportunistic patenting by other pool members. The problems of pool creation have triggered initiatives by SSOs and consortia to facilitate timely agreement on pool licensing. Furthermore, companies have engineered innovative organizational designs for new patent pools. The most striking example is the One-Blu pool licensing scheme for BluRay patents. This pool is indeed a "pool of pools", including patents for various complementary standards. Furthermore, the pool includes new rules on differentiated remuneration of different kinds of essential patents and restricts the possibilities to introduce various patents related to the same invention. These mechanisms deviate from the practices previously cleared as pro-competitive in the 1997 and 1999 business review, thus giving rise to a renewed policy interest in patent pools.

Another mechanism for addressing problems generated by essential patents is upfront coordination of standard-related R&D through informal consortia and alliances. Informal consortia have long been conceived as competitors for formal SSOs. While formal SSOs deliver standards with a strong legitimacy facilitating wide implementation, the discussions inside their working groups are reputed to be tedious and lengthy. The consensus decision making of SSOs is prone to wars of attrition, time-consuming battles between different stakeholders trying to push their patented technology into a standard. These standard battles also burn precious resources, as companies duplicate R&D efforts in races to assure control over as many standard components as possible. Informal consortia and alliances of firms with a common objective can be much faster and more efficient in streamlining R&D. While consortia have sometimes successfully competed with formal standards, more recently, formal SSOs have increasingly understood to value informal consortia as complement rather than a competitor to formal standardization. Several formal SSOs have accredited consortia as members, signed liaison agreements for cooperation on single standardization projects, and even engaged into long-term alliances with informal consortia.

In sum, the emergence of the institutional framework for standardization of proprietary technology can be described as a bottom-up process, a series of increasingly incremental industry-driven organizational innovations. Many of the institutional features result from discretionary choices. The strong initial opposition to FRAND policies by open source communities and liberal business advocates reveals that the choice of essential patents as sui-generis regulatory principle was not an uncontested unique solution. But since then, policy makers and practitioners have invested heavily in defining what FRAND means, in innovating solutions to specific related problems, and not least in subsidizing economic research analyzing the effects, incentives and strategies induced by essential patents. Twenty years after its beginnings, there is no available alternative to the regulatory principle of essential patents which is comparably refined and well-understood.

This fact is mainly due to the specific policy landscape in which the regulatory framework for standardization has emerged. ICT standardization takes place on a worldwide scale, and is driven by firms and a continuously growing number of diverse SSOs. A fundamental institutional innovation could only be assured by overarching institutions that are robust to institutional change and can coordinate organizational investment by many different actors. In many fields of economic policy, national governments and bureaucracies successfully play this role of catalysts of institutional innovation. In our field of interest, only competition policy has provided a policy framework for organizational progress. The specific obligations ascribed to holders of essential patents and the clearly circumscribed rules for the creation of patent pools both are enforced by antitrust policy. However, the role of competition policy is necessarily limited and confined to restrictive measures. Economists have for instance proposed auction mechanisms (Swanson and Baumol, 2005) or non-assertion policies (Rysman and Simcoe, 2011) to substitute for the vague FRAND commitments. There is however no overarching regulatory framework in which such mechanisms, designed from the scratch and founded in economic theory, could be enforced. Therefore there is no alternative to the continuous, bottom-up progress of the institutional setup through local solutions to specific problems. This must be borne in mind by the economic researcher who aims to contribute to improving the system through his policy recommendations.

4. Review of the relevant economic literature

The continuous progress of the regulatory framework for standardization is indeed increasingly informed by a growing body of economic literature specializing on the analysis of technological standards. The economic research can be roughly divided into three strands of literature, culminating respectively at the end of the 1980s, at the end of the 1990s and in the past couple of years.

The first period of research is dominated by theoretical analysis. The theoretical economic literature on technology standards dates back to the seminal articles of Farrell and Saloner (1985, 1986). These articles initiated an important strand of literature (Katz and Shapiro, 1986, Matutes and Regibeau, 1992, Economides, 1996, Kristiansen, 1998, Clemens, 2005), which has analyzed the basic mechanisms underlying the economics of compatibility, network effects and the dynamics of standard adoption. A contribution of this strand of literature which has been particularly important for my thesis is the finding in Katz and Shapiro (1985) that sponsorship of standards, i.e. a firm holding exclusionary property rights on the standardized technology, can overcome excessive inertia in the spread-out of innovative standards. Notwithstanding its importance, this literature is however characterized by the striking absence of standard setting itself. Indeed, standardization is analyzed as a convergence of markets on a network technology, as a result of the choices of uncoordinated consumers between technologies provided by single firms. Eventually, Farrell and Saloner (1988) introduce an abstract SSO in the models – a consensus based decision making process, which can substitute for the market mechanisms. This model however still characterizes an ideal-typical SSO akin to a social planner.

The second strand of literature is driven by the empirical features of real world standardization, and consists mainly in qualitative analysis. The literature on path dependency, initiated by Arthur (1989), spurred strong interest in the dynamics of the technological progress of standards. In this debate, Liebowitz and Margolis (1994) raise the argument that strong IPR provide a safeguard against inefficient path dependencies. The idea of path dependency in the technological evolution of standards is largely explored in the evolutionary literature on technological trajectories, for which the analysis of standards provides empirical support (Metcalfe and Miles, 1994, Bekkers and Martinelli, 2012). Another focus of interest lies on the competitive strategies in standardization. Besen and Farrell (1994) analyze the rich set of strategies in the competition between standards and between technologies inside a SSO. Case studies on recent standardization projects (Bekkers, 2001; DeLacey et al., 2006) discuss into details the strategies induced by the inclusion of essential patents. Lemley (2002) provides a detailed overview over the rules on essential patents in various SSOs. This strand of literature has yielded two special issues on standardization in important journals and a first anthology of the economics of standards (Blind, 2004). Most importantly, this literature has considerably broadened the scope of the analysis of standards : indeed, standards' economic role does not resume in ensuring compatibility between goods in a network, but standards are comprehensive coordination tools in innovation – they ensure reduction of variety and mitigation of risks. Standard setting is understood as part of a joint innovation effort combining competition and collaboration (Besen and Farrell, 1994).

My Ph.D. thesis is part of a more recent stream of analysis combining the qualitative insights on real world standardization with the fundamental theoretical models, yielding a quantitative empirical analysis of standardization grounded in formal economic models. These models picture SSOs as complex economic institutions, characterized by a formal decision making process (Farrell and Simcoe, 2012). Furthermore, it is understood that the rules of SSOs are the result of the rivalry between SSOs, competing to attract holders of valuable technology and potential users alike (Lerner and Tirole 2006). These models can be successfully applied to the analysis of the speed of standard setting in real world SSOs such as the IETF (Simcoe, 2012), and to economically explain the rules of a large variety of contemporary SSOs (Lernier, Chiao and Tirole, 2007).

Furthermore, the recent literature increasingly focuses upon the quantitative analysis of strategies relating to the interface between patents and standards. While the interest initially focused upon the vagueness of FRAND royalty terms (Lévêque and Ménière, 2008) and attempted an economically grounded clarification (Swanson and Baumol, 2005), there is a trend towards a more comprehensive analysis of patenting and standardization strategies (Blind and Thumm, 2004). The analysis of the inclusion of essential patents into technological standards is formalized by Layne-Farrar et al. (2011) and Tarantino (2011), who describe the SSO as a coalition to build standards by acquiring technology competitively provided by innovators. Several recent contributions empirically investigate the incentives and strategies of these innovators. Rysman and Simcoe (2008) highlight the increase in the value of a patent induced by its inclusion into a standard, Bekkers (2012) analyzes the factors determining that a patent is included into a standard, Berger et al. (2012) shed light on patenting strategies used to match patents with ongoing standardization and Ganglmair and Tarantino (2012) study the timing of patent essentiality declaration. There is thus an increasing body of research analyzing the driving factors of the increasing number of essential patents. The consequences of essential patents for standardization are however still poorly understood.

In parallel to the advancing research on standardization, many recent economic analyses have shed light on the emergent coordination mechanisms related to standards and essential patents. Shapiro (2001) describes SSOs, consortia and pools as a way to navigate through thickets of overlapping patents. Especially the growing number of patent pools has triggered much formal theoretical analysis. Lerner and Tirole (2004) provide an economic justification for the assumption that the current patent pools are welfare-enhancing. Other important contributions analyze the difficulties in building coalitions for patent pools (Aoki and Nagaoka, 2004, Brenner, 2009, Lévêque and Ménière, 2011), the effect of patent pools on innovation incentives (Dequiedt and Versaevel, 2012, Aoki and Schiff, 2007, Llanes and Trento, 2010, Schmidt, 2010) and the effect of patent pools on the incentives to file and litigate weak patents (Choi, 2011, 2012). The more scarce empirical literature analyzes which rules are adopted by what kind of rules (Lerner et al., 2007) and how the rules of patent pools determine firms' decision to join (Layne-Farrar and Lerner, 2011). Other recent analyses study the impact of pools upon the efficiency of patent enforcement (Delcamp, 2012) and on subsequent patenting and technological progress (Lampe and Moser, 2010, 2011, 2012 for historical patent pools, Joshi and Nerkar, 2011-1). There is so far however no empirical analysis of the effect of prospective patent pools on the incentives to file essential patents to be included into a pool.

In contrast to patent pools, and in spite of their high number[6] and significant importance, informal standardization consortia have received little attention in the economic literature. Several qualitative contributions have analyzed the emergence of new consortia, the competition between consortia and formal SSO, and the strategies of optimally combining formal and informal standardization (Cargill and Weiss, 1992, Updegrove, 1995, Hawkins, 1999, Cargill, 2002). The first formal analysis of the interplay between SSOs and informal consortia however dates back only to Leiponen (2008), who shows that participation in informal consortia increases firms' ability to influence formal standardization. Blind and Gauch (2008) show on a firm level that membership in consortia and formal SSOs is complementary, and Delcamp and Leiponen (2012) find evidence that consortia coordinate the R&D efforts of their members. While these contributions shed light on the benefits for companies to join informal consortia, there is so far no empirical analysis of the effect of consortia on the overall efficiency of standardization.

In spite of its diversity, the contemporary economic research on standardization is characterized by important binding elements, which have also guided my research for this thesis. This literature has shifted the focus of the analysis from the coordination of

[6] 700 consortia are currently listed in the CEN standardization survey and in the list updated by Andy Updegrove

technology adoption decisions in a network of users towards the coordination among innovators in the development of new technology. The literature has furthermore moved from a dichotomy between abstract economic models and qualitative empirical work towards a formal quantitative empirical analysis grounded in explicit economic models. Furthermore, the focus of attention of economic research has moved on with the policy debates, continuously integrating emergent economic mechanisms and institutions. The theoretical and empirical research got closer in time to the emergence of the issues; and thus increasingly synchronous with the relevant policy debates.

Over time, the economic research has increasingly taken part in the process of institutional innovation. Economic models such as Lerner and Tirole (2004) have been rapidly absorbed by policy makers, and there are now a considerable number of venues for a dialogue between policy makers, stakeholders and economic researchers[7]. In order to inform policy making, abstract economic reasoning needs to be applied to precise, technical real world situations in a continuously evolving institutional context. This is a deep challenge especially for quantitative, empirical work. In order to increase the reliability of the empirical research, it is necessary to gain some distance, to let the evidence accumulate and to fully observe even the long term effects – but in the meantime the process of institutional innovation moves further, and if the evidence is presented too late, the issues are already irreversibly settled. The empirical researcher needs to strike a balance between the robustness of his results, and the timeliness of his contribution. To circumvent this tradeoff, empirical economic research has sometimes used historical evidence to inform current policy debates (for instance Lampe and Moser studying 19th century patent pools). Nevertheless, the insights that can be drawn from historical data for contemporary problems are limited. FRAND licensing commitments, informal standardization consortia and ICT patent pools are contemporary and unique institutions which have evolved as a part of the specific institutional architecture around essential patents in ICT standardization. Decision making with respect to these institutions and the related mechanisms needs to rely upon the short-lived empirical evidence on contemporary phenomena. This evidence is however seriously limited, as essential data is missing, and facts and figures are open to various speculative interpretations. There are thus today two important tasks for empirical economic research: first, produce robust quantitative data, and second, gradually restrict the range of possible interpretations for the revealed facts through econometric techniques.

[7] A regular exchange of ideas between standardization practitioners and economic researchers for instance takes place at the Standardization and Innovation in Information Technology (SIIT) Conference, where two chapters of my thesis have been presented. I also presented my findings to IPR practitioners at the EPO/OECD conference « Patent Statistics for Decision Makers », and I communicated policy implications of my research to the European Commission through a public consultation by DG Competition.

5. The contributions of this dissertation

My Ph.D. thesis contributes to the literature on standardization and innovation through a thorough econometric analysis of a rich set of novel and original data. These data allow addressing important empirical questions, which have so far found no satisfactory response. This thesis provides empirical evidence on the distinctive characteristics of essential patents, on how investment in essential patents is affected by patent pools and informal consortia, and on the effect of essential patents on the technological progress of standards.

The Ph.D. thesis is organized along three research axes. The first axis analyzes the specific characteristics of essential patents, reflecting their role as original appropriation mechanism. The first chapter of the thesis highlights that, among essential patents, the technological significance of the underlying invention is uncorrelated with measures of the private value of the patent. This finding provides an economic foundation for the analysis of the *patent inflation* – a multiplication of increasingly insignificant essential patents watering down the value of the significant inventions. I furthermore show that this effect is confined to the sample of essential patents, and cannot be generalized to the so-called complex technology classes. The chapter also makes a methodological contribution through an assessment of patent quality indicators for research on cumulative innovation. I highlight that while the number of forward citations is the most meaningful indicator in the case of discrete innovation, the number of claims and the generality index are more relevant in the case of cumulative innovation. This finding has guided the methodology of the following analysis.

The second chapter analyzes the characteristics of essential patents introduced into patent pools. Patents added to the pool over time are increasingly narrow, incremental and insignificant. The patents introduced by incumbent pool members are narrower and less significant than patents introduced by new entrants. Using a novel indicator, I furthermore show that patents introduced into the pool over time are increasingly focused upon the standard underlying the pool, and that incumbent members introduce patents which are more focused upon the standard. I discuss the hypothesis that the royalty sharing rules practiced by these pools, which do not account for the significance of the underlying invention, induce opportunistic patenting on standard-essential technology. Incumbent members could hereby benefit from a better access to the pool, for instance through a learning on the criteria of essentiality. I also discus alternative explanations for these findings: founding members of pools are coalitions of firms who have developed the technological core of the standard. The central position of these firms, independently from the creation of a pool, allows them to obtain a large number of standard-essential patents. Another explanation is that the creation of a patent pool streamlines further technological development of the standard towards the technologies which are available from the pool.

The second axis measures standard-related patenting, and analyzes how the incentives to obtain standard-essential patents are affected by patent pools and informal standardization consortia. The third chapter of the thesis discusses empirical evidence for the effects of prospective patent pool creation on standard-related patenting. So far, there is only empirical evidence on the effects of pooling existing patents upon follow-up patenting. The theoretical literature however focuses upon ex ante effects of expected patent pool creation on the incentives to file patents that could be included into this pool. We find evidence supporting the predictions that prospective patent pool creation induces an increase in related patenting. Furthermore, we show that standard-related patenting is anticipated with respect to the usual timing when a patent pool is expected. Nevertheless, we argue that the possibility to create patent pools is not a significant driver of the increasing number of essential patents.

The fourth chapter shows that depending upon the IPR policy, collaborative R&D for technology standards can be characterized by either under-investment or over-investment. If rewards for essential patents are insufficient, the public good nature of the standard induces free riding and underinvestment, while excessive rewards induce patent races and over-investment. Informal standardization consortia streamlining the collaborative R&D effort not only increase the R&D efficiency of their members, but can also attenuate either type of inefficiency. Using the participation of non-practicing entities to identify standards characterized by over-investment, we find that the effect of consortia membership on standard-related patenting is always positive in cases of under-investment, whereas it is weaker or even negative in cases of over-investment.

The third research axis analyzes the consequences of the inclusion of patented technology on the dynamics of standardization. The fifth chapter of the thesis shows that the inclusion of patented technology into a standard increases the expected lifetime before standard replacement, but induces more frequent upgrades of existing standards. Essential patents thus induce a more continuous technological progress, while reducing the incidence of fundamental changes to the incorporated technology. While more frequent standard upgrades can partly explain the effect of essential patents on the rate of standard replacement, we still find evidence for a significant effect of patents on the expected lifetime of standards even when controlling for the frequency of upgrades. This finding indicates that essential patents also contribute to slowing down standard replacement through other mechanisms, such as rent-seeking strategies and vested interests in standard development.

In addition to providing empirical responses to specific research questions, my research sheds light on the more general interaction between standardization and technological progress. In the analysis of the various novel phenomena at the interface between patents and standards, I develop an integrated and original conception of standardization and clarify the distinctive economic function of essential patents. In my analysis, standardization is a selection mechanism, selecting certain technological elements as the basis for further technological progress. Standardization is thus an integral part of the process of cumulative innovation. In vast parts of the literature, standardization is analyzed as an adoption decision, as a choice among existing technological options. In the chapters of my thesis, I show that standardization accompanies and often precedes the relevant R&D effort. I also analyze standards as dynamic objects: in contrast to patents, standards evolve, and constantly change. A second distinctive feature of my analysis is the conception of essential patents as a very specific appropriation mechanism. Indeed, rather than property rights on distinct bits of technology, essential patents function as claims on the fruit of joint work. Obtaining an essential patent on a standard means obtaining a say on the future of the standard. Essential patents are the basic instrument for bargaining and contracting on the levels of future investment and shares in the expected revenue. In the same line, including patented technology into a standard means more than just acquiring a useful invention. It also means gaining a new sponsor for the standard, and to the worse or the best, it means gaining a new member of the family of stakeholders.

My thesis does however not provide a settled theory of the role of essential patents. I like to think of this research as a contribution to the ongoing cumulative effort to understand the interface between patents and standards. It consists in five research papers, streamlined towards the open gaps in the relevant literature by the selection mechanism operating through the review process of academic journals, and coordinated through helpful discussions with academic colleagues in twelve international conferences. At this place, I should acknowledge that I have integrated comments and suggestions from various anonymous referees, the discussants at the different conferences, and my colleagues at Mines ParisTech, TU Berlin and Hitotsubashi University. Reiko Aoki, Rudi Bekkers, Marc Bourreau, Nancy Gallini, Tobias Kretschmer, Anne Layne-Farrar, Aija Leiponen, Sadao Nagaoka, Mark Schankerman, Tim Simcoe and many others that I forget have provided helpful support and suggestions in discussions and emails. The different papers are co-authored on equal basis with Knut Blind, Henry Delcamp, Yann Ménière and Tim Pohlmann. Overall, this thesis is a genuine part of a process of distributed innovation in the spirit of my analysis.

Chapter I : The Private and Social Value of Patents in Discrete and Cumulative Innovation

La valeur privée et sociale des brevets en innovation discrète et cumulative

Cet article analyse le rapport entre valeur privée et sociale des brevets, en comparant l'innovation discrète et cumulative. Il est établi que les indicateurs de la valeur sociale des brevets sont moins corrélés avec les indicateurs de valeur privée dans des champs technologiques caractérisés par un type d'innovation plus cumulatif. Nous analysons si ce résultat est du à un lien moins fort entre valeur privée et valeur sociale, ou si les indicateurs sont eux-mêmes moins aptes à mesurer les différents concepts de valeur. Par ailleurs, nous analysons si cette spécificité de certains champs technologiques est réellement imputable au caractère cumulatif de l'innovation. Nous observons l'innovation cumulative grâce à des bases de données de brevets déclarés essentiels à des standards technologiques. En utilisant l'analyse factorielle et un ensemble d'indicateurs de qualité de brevets, nous estimons l'importance de la valeur sociale pour déterminer la valeur privée d'un brevet, mesurée à travers des données de renouvellement et de litiges. Alors que nous trouvons une corrélation robuste et significative entre valeur privée et valeur sociale dans le cas de technologies discrètes, ni les facteurs communs, ni les indicateurs spécifiques de la valeur sociale permettent de prédire la valeur privée dans le cas des brevets essentiels, issus d'un type d'innovation très cumulatif. Néanmoins, ce résultat ne peut pas être généralisé à des classes technologiques entières classifiées comme classes de technologies complexes par la littérature.

1. Introduction

Patents play an important role in modern economies, especially in the growing sector of Information and Communication Technologies (ICT). At the same time, ICT patents are seen with increasing suspicion. One important source of concern is the importance of cumulative innovation in ICT. For the purpose of this inquiry, cumulative innovation is defined as a process whereby various strongly complementary inventions need to be bundled together for any commercial application. In technological fields where cumulative innovation is dominant, patents do not provide their owner with a monopoly right over a marketable invention, but rather with a blocking power over a jointly controlled technology. This could explain why the economic literature has evidenced different patenting strategies in technological fields such as ICT or software than in other technologies (Cohen et al., 2000). For instance, recent research highlights the importance of strategic patenting in these technological fields (Bessen and Hunt, 2003; Noel and Schankerman, 2006). It is a widely shared belief that an important share of the numerous patents filed in these fields is of questionable value (Jaffe and Lerner, 2004). Furthermore, there is skepticism about the contribution of these numerous patents to technological progress (Bessen and Maskin, 2006). Many scholars raise concerns that cumulative innovation in ICT might be stifled in a dense "patent thicket" [8] (Shapiro, 2001) with many low quality patents having a blocking capacity.

For many economists, the patent thicket problem weakens innovation incentives by reducing returns on significant innovations through patent inflation and litigation, while allowing litigious firms to earn much on patents of dubious technological significance (Shapiro, 2001; Bessen, 2003). The core prediction of this theory is thus that the link between the social value and the private value of the patent for its owner erodes. Social value of a patent designates the contribution of the underlying invention to social welfare[9], including both future technological developments and the value of current commercial applications. As opposed to social value, the private value only encompasses the value of a patent for its owner.

The link between the private and social value of patents is important for the capacity of the patent system to reward innovators for socially desirable innovations. If the link is weakened,

[8] Patent thickets can be defined as: "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology." (Shapiro, 2001)

[9] The earlier literature often refers to a broader concept of "patent quality". Nevertheless, the concept of patent quality lacks a clear definition. We will therefore stick to the better defined concept of patent value, and rely upon the traditional distinction between private and social value of inventions. This distinction dates back at least to Arrow (1962).

the patent system is at risk to encourage strategic patenting on incremental contributions rather than inventive efforts and significant innovations. We will therefore address the crucial issue of the link between private and social value of patents with a special focus on cumulative technologies.

Probably one of the most prominent examples of cumulative technologies is ICT standardization. Standards are means of ensuring compatibility between complementary technological components. Standardization is thus a crucial feature of cumulative innovation. Standard setting has evolved to an original form of joint development of common technological platforms in highly profitable markets such as mobile telephony, wireless communication, digital data processing and consumer electronics. The question whether the patent system is able to appropriately reward innovators for their contributions to this cumulative technological innovation is a crucial policy issue. This is evidenced by the debates around sharing of royalty surplus between the owners of patents included into standards (Swanson and Baumol, 2005; Salant, 2009). Therefore, standardization is a perfect way to identify patents on cumulative inventions, even though not all cumulative sectors are subject to standardization.

Going beyond the narrowly defined, yet extremely important, technology markets around formal standardization, there are attempts in the literature to identify broader technological fields in which technology is more cumulative. Many authors have relied upon the technological classification of patents by patent examiners, proposing a categorization in discrete and complex technology classes. In this definition, the difference between complex and discrete technological classes is that a complex class is characterized by stronger cumulativeness[10]. Even though the concrete classification varies from study to study, ICT technologies are consistently classified as complex. ICT is indeed characterized by high citation rates among patents, indicating strong cumulativeness of research (Nagaoka, 2005), and it concentrates the majority of mutually blocking patent rights (Von Graevenitz et al. 2009).

In several empirical studies[11] on the capacity of indicators of the social value of patents to predict private value, electronics and other "complex" technological fields have revealed a low link between measures of private and social value. Nevertheless, these studies do not reveal whether the capacity of social value indicators to predict measures of private value is

[10] See for instance Cohen et al. (2000), p. 19: "[…], the key difference between a complex and a discrete technology is whether a new, commercializable product or process is comprised of numerous separately patentable elements versus relatively few"

[11] E.g. Hall et al. (2005) and Lanjouw and Schankerman (1999), for a more detailed literature review, see Part I.

weaker because the link between private and social value is weaker, or because the indicators are themselves less informative of the underlying concepts of value. Furthermore, none of these studies has clearly established whether cumulativeness per se is driving this apparently lower link between indicators of the social and private value of patents, or whether other specificities of technological classes classified as “complex” could be the reason for these results.

It is an important contribution of the present study to disentangle these issues. First, we analyze whether the observed differences in the relationship between measures of private and social value are due to differences in the performance of indicators to measure the underlying concept, or in the link between the concepts themselves. Therefore, in this study we will use a broad range of indicators to measure the social value of patents: forward citations, backward citations, number of claims, family size, and originality and generality indices. We observe the private value of patents by predicting the likelihood of renewal after 4, 8 and 12 years of patent terms and check the robustness of our results by using litigation data as alternative measure of private value[12]. We are thus able to disentangle the link between private and social value from the performance of indicators.

Second, we analyze whether these differences between patents in complex and discrete technology classes are due to the cumulativeness of research. For this purpose, we compare random complex technology patents to patents that are essential to technological standards and thus perfect examples of cumulative innovation. We will therefore study three different samples of patents. The first sample consists of patents declared as essential to technological standards, and allows testing directly the characteristics of cumulative innovation. In order to analyze whether these effects can be generalized to the broader technological field, we compare our sample of essential patents with a control sample of sibling patents from the same technological classes as the essential patents, classified as complex by the related literature. Finally, we introduce a third sample of patents with the same application years as our two other samples, but randomly drawn from patent classes that are consistently classified as discrete by the related literature. We then compare the link between the private and social value of patents from sample to sample.

The remainder of this article is organized as follows. Part I summarizes the literature and sketches our main contributions to the state of the art. Part II describes the data and discusses the construction of the samples. Part III summarizes the results of the factor analysis. In Part IV, we will describe how the quality factor performs in predicting patent

[12] for a discussion of these measures of patent private value, see Lanjouw and Schankerman, 1999 and Bessen, 2006

value as measured through patent renewals. Part V discusses the implications of our results for policy and research methodology.

2. Analytical framework

It is the aim of this part to provide an overview over the literature and to sketch our main contributions to the state of the art. In the first part, we summarize the economic literature on the measurement of the social value of patents, and in particular the use of patent indicators. In the second part, we discuss results of previous studies using these indicators to analyze the relationship between private and social value. In both parts we focus particularly on the distinction between discrete and cumulative innovation. In the third part, we show how the present study goes beyond and complements the previous findings.

2.1 Measuring the social value of patents: the literature on patent indicators

There is a longstanding tradition in economic research to measure the output of innovative activity with patent data. Nevertheless, patents are very heterogeneous, as some patents are very important, while many patents are never used. As this heterogeneity of patents reduces the significance of patent counts as measure of innovation output, empirical research seeks for ways to weight patent counts by measures of the social value of the patents.

Various strategies exist to compare the social value of patents: the literature has used e.g. expert rankings, case studies, or survey analysis. Nevertheless, these strategies are not available for studies of broad technological sectors with a very high number of relevant patents. Therefore the economic literature systematically relies upon indicators of patent quality. Indicators are quantitative patent characteristics that are easily observable and are thought to reflect their social value.

The most commonly used indicators are the number of citations a patent receives by posterior patents (so-called forward citations), the number of claims, and the size of the patent family (i.e. the number of international patent files with the same priority patent) (Griliches, 1990). Other indicators of social value include the number of backward citations, i.e. the number of patents cited as prior art and the patent's generality index (measuring the dispersion of prior art over technology classes) and originality index (measuring the dispersion of citing patents over technology classes). Table 1 summarizes the main indicators used in the literature.

Name of the Indicator	Description	Justification
Forward citations	Number of citations received by posterior patents	Indicates the relevance of the patent for further research
Backward citations	Number of citations made to previous patents	Indicates the extent to which the patent makes use of the existing prior art
Number of claims	The number of priority claims made in the patent	Indicates the breadth of the technology claimed by the patent holder
Family size	The number of international patents filed for the same priority patent	Indicates that a patent is important on an international scale, and that the validity of the patent has been certified by various patent offices
Generality	Dispersion of cited patents over technology classes	Indicates that the patent draws from various sources, increases the likelihood that the patent is a fundamental rather then incremental innovation
Originality	Dispersion of citing patents over technology classes	Indicates that the patent has been important for a broad field of further research

Table 1: Patent quality indicators

These indicators are often used indiscriminately in different sectors and to measure a vague and little defined social value of patents. However, the indicators capture at best heterogeneous phenomena associated with this social value. For example, the number of claims could indicate the breadth of a patent whereas forward citations measure technological significance for further research. These specific phenomena could be, according to the field and the aim of the study, more or less relevant. Thus, these indicators may be, according to the sector, considered as more or less suited to a study of a specific situation. Consequently, assessing the reliability of social value indicators is crucial.

For instance, the performance of the forward citations indicator has been repeatedly assessed and confirmed. Trajtenberg (1990-1) shows on a sample of computed tomography patents that more highly cited patents contribute more to consumer and producer welfare, Harhoff and al. (1999) show that patent holders value higher those of their patents that receive more citations, and Giummo (2003) finds that patents more often cited are more likely to be licensed. It has furthermore been shown that patents cited more frequently are more likely to be litigated (Lanjouw and Schankerman, 1999) or to be included into technological standards (Rysman and Simcoe, 2008). In a different approach, Lanjouw and Schankerman (2004) carry through a factor analysis on four indicators of social value and identify a strong common variability with one single common factor capturing an important part of the variance in the data. They argue that patent "quality" is the only underlying factor that could be thought of to jointly affect the number of claims, forward and backward citations and the size of the families. They furthermore argue that using a common underlying factor of various indicators rather than a single indicator allows reducing the noise and improves the capacities of indicators to approximate patent "quality".

Probably, the most important challenge to the general use of patent indicators is the heterogeneity of the patent population. The functions and the mechanisms of patents can vary very much according to external factors, such as the type of assignee, the grant year and especially the field of technology. It is important in our context to make sure that for instance cumulativeness does not affect the capacity of indicators to measure the social value adequately.

For several reasons the cumulativeness of a technological field could have an impact on the measures used as indicators of social value of patents. For instance, the cumulativeness of innovation mechanically affects the average number of forward citations (Nagaoka, 2005). Indeed, a patent has a higher chance of being cited in a technological field where technological inventions strongly build upon each other. For the same reason, a patent in such a dense web will have to cite more previous art than a comparable patent in another technological field.

Also patenting strategies are different from discrete to cumulative innovation, which could have an impact on specific indicators. For instance, in cumulative innovation, not all complementary parts of a technology need to be patented in every single office in order to exclude potential imitation. Therefore patent families are larger in discrete than in cumulative innovation. Furthermore, the existence of overlapping patents in cumulative innovation could provide incentives to raise the number of claims, as increasing the number of claims increases the chances of the patent to be relevant to future developments of a jointly held technology (Berger and al., 2012).

The fact that the indicators are driven upwards or downwards by the cumulativeness of innovation in a particular technological field does not impede that variance inside a sample of patents from this technological field indicates differences in the social value of patents. For instance, Lanjouw and Schankerman (2004) in their factor analysis of four indicators over samples of patents from different technological fields identify a “quality” factor that is roughly consistent over technological differences. Nevertheless, the common variability of the indicators captured by this factor is lower in electronics, and the relative weights of the different indicators included in the factor are different. These results could indicate that even though the indicators still evidence a common “quality” factor in complex technology classes, they yield less consistent results in these sectors where innovation is more cumulative.

The reviewed literature provides several arguments why patent indicators perform differently well in measuring the social value of patents in discrete and cumulative innovation. It is therefore important to test the consistency of patent indicators across different technological fields before analyzing differences in the link between the social and private value of patents.

2.2 The link between private and social value of patents: cumulative vs. discrete innovation

Economic research draws a clear distinction between private and social value of inventions (Arrow, 1962; Trajtenberg 1990-2). As mentioned before, the social value represents the total net value created by the patent for social welfare. The concept of private value takes into account only the value added of the patent for its owner: it can thus be defined as the depreciated sum of expected cash flows or the contribution of the patent to the market value of the owning firm. The private value can also be expressed as the social value minus all positive[13] and negative externalities[14] (Bloom et al., 2010). The social value is thus a causal determinant of the private value of the patent. Private value is furthermore determined by the ability of the owner to appropriate the value generated by the patent and to exclude the generation of positive externalities (Trajtenberg et al., 1997). On the other hand the private value can also exceed the social value of patents, if additionally to reaping the added value of the protected technology they allow leveraging on related innovations, for instance in the case of patent thickets.

In a very complete review of the literature, Van Zeebroeck and Van Pottelsberghe de la Potterie (2011) highlight the conceptual difference between determinants and indicators of patent value. Indeed, the empirical literature relies upon statistical patent indicators as measures of private patent value. As discussed, the same patent characteristics are as well used to measure the social value of patents. As such, they are often determinants rather

[13] such as for consumers, intermediaries, and follow-up inventors
[14] such as the effect on the profits of a competitor

than indicators of private patent value. The use of a specific variable as indicator of private or social value of patents depends upon the research setting. Recent research (Lanjouw and Schankerman, 2004; Bessen, 2006) focuses upon patent renewal and litigation decisions as measures of private value, as costly renewal and litigation decisions reveal a minimal threshold value of the patent to its owner. Thus, the private value of patents is measured indirectly, through the observation of the behaviour of the agents, which reveals the value that they attribute to their patent. The remaining observable characteristics, such as technological significance as measured by citations, the breadth of the patent as measured by the number of claims, and application strategies such as family size, are used to represent the social value of patents. Assuming a correlation between social and private value, these indicators can thus be analyzed as causal determinants of private value.

An increasing strand of empirical literature has studied the link between private and social value of patents. Hall et al. (2005) and Nagaoka (2005) analyze the correlation between patent indicators reflecting the social value of patents and the market value of the patent owner, and Lanjouw and Schankerman (1999) and Thomas (1999) analyze the impact of patent "quality" indicators on the probability that a patent is renewed. Consistently, all studies evidence a strong link between private and social value, but there is also evidence for strong differences across technological fields.

Many arguments pointing to a divergence between the private and social value of patents relate to the cumulativeness of research. Different strands of research have established that firm strategies with respect to patents differ from cumulative to discrete technologies. In cumulative technologies, many firms use patents for other reasons than excluding their rivals from the use of their technology (Cohen et al., 2000). Most notably, many firms active in cumulative technologies rely heavily on cross-licensing agreements to cut their way through patent thickets (Shapiro, 2001) and engage into patent portfolio races (Hall and Ziedonis, 2001). Hereby patent portfolios play an important role as "mass of negotiation".

Thus, the way how patents create value could be different from discrete to cumulative technological fields. According to this argument, the value is not only derived from the use of the technology, but from the possibility to use the patent as a threat of exclusion and mass of negotiation. The possibility to use patents as bargaining chips has two implications on the private value of patents: first, there is an incremental value to holding a patent in cumulative innovation which is independent of the social value of the underlying invention. In line with this hypothesis, Liu et al. (2008) find that patents relating to sequential innovation held by the same owner are more valuable. Second, in cases of cumulative innovation, the private value of the patent for its holder is less determined by the intrinsic significance of the underlying invention. For instance, Noel and Schankerman (2006) find evidence that the contribution of software patents to firm value depends upon fragmentation of patents in patent thickets and upon strategic patenting by competitors. In very cumulative innovation, and most notably in the realm of telecommunication standards, the perceived disconnection between the social value of patents and the royalty revenue that they generate for their owner has spurred a long series of litigation and regulatory efforts[15].

Consistently with these arguments, several empirical findings highlight weaker links between indicators of private and social value of patents in "complex" technological classes, where cumulative innovation is assumed to be more important. These contributions build upon the idea that technologies can be categorized into complex and discrete technologies, whereby complex technologies are characterized by a dominance of cumulative innovation and a strong incidence of patent thickets[16]. This distinction originates in a paper of Levin et al. from 1987 and has by now been studied by an extensive body of research[17].

Lanjouw and Schankerman (1999) use a compound factor of "quality" indicators (claims, forward citations, family size and backward citations) to predict patent litigation and renewal as measure of private value. They emphasize a strong link between patents' private value and indicators of "quality"; but this link is less obvious for the electronics sector. Hall et al. (2005) underline that the impact of citations on the contribution of patents to the firms' market value differs according to the type of technology. They especially highlight that the impact of patent citations on market value is over 50% higher for drugs than the average effect. This effect is lower for computers than that for the other sectors. They explain this difference by the cumulativeness of innovation: "*Computers and Communications is a group of complex product industries where any particular product may rely on various technologies embodied in several patents held by different firms. In this industry patents are largely valued for negotiating cross-licensing agreements, so their individual quality is not as important, although having them is*". On the other hand, Nagaoka (2005) finds that forward citations are more correlated with firm market value in ICT and other industries where innovation is cumulative.

[15] There is an increasingly precise regulatory framework for licensing patents in these very cumulative technologies, as it is not clear that market mechanisms will yield prices that are in adequate proportion to the technological contribution of the patent. A recent example is the drastically extended chapter on standardization in the draft guidelines on the applicability of European Competition Law to Horizontal Cooperation Agreements, see http://ec.europa.eu/competition/consultations/2010_horizontals/guidelines_en.pdf
16 Harhoff et al. (2008)
17 Levin et al. (1987), Merges and Nelson (1990), Cohen et al. (2000)

2.3 Our contribution to the state of the art

The empirical literature has repeatedly found differences in the link between indicators of private and social value of patents between technological classes. These differences have been widely attributed to implications of more or less cumulative innovation, as theoretical arguments predict a weaker link between private and social value of patents when innovation is cumulative. However, the empirical validation of this hypothesis faces two methodological challenges. First, it is necessary to make sure that the measurement of private and social value is consistent throughout the samples to be compared. In previous studies, differences between discrete and cumulative innovation have been either attributed to measurement issues, regarding the performance of indicators (e.g. Lanjouw and Schankerman, 1999), or to economic differences in the link between private and social value (e.g. Hall et al. 2005). Second, it is not straightforward to identify cumulativeness of innovation. Previous studies have relied upon patent classification into complex and discrete patent classes, but it is unclear to what extent technological classes can capture higher or lower degrees of cumulativeness[18]. It is the main contribution of our paper to jointly resolve these two methodological challenges.

We address the first point running a factor analysis to identify the common variance of patent indicators. We can thus test in a first stage the consistency of patent indicators in the different samples, and use the underlying factors rather than single indicators as measures of social value. With respect to previous studies, we enlarge the set of indicators, by adding generality and originality indices to the traditional indicators. In the factor analysis, we will allow for two rather than one common factor, in order to capture a broad concept of social value.

We have defined social value as the contribution of a patent or the underlying invention to social welfare. The first aspect of the social value of a patent is thus the impact of the underlying invention on current welfare and future technological progress. Nevertheless, we argue that when inventions are cumulative, it is unclear whether it is possible to assess their individual social value in terms of impact. Indeed, the idea of cumulativeness implies that each single invention is necessary to allow the bundle of inventions to have an impact. In

[18] Indeed, the notion of complex technology fields seems problematic in light of e.g. recent evolutions in the field of biotechnology. Biotechnology comprises a set of technological advancements in the field of medical drugs, plant breeding and crops. These technological fields are traditionally classified as discrete. Biotechnology itself however is characterized by an important degree of cumulativeness, with strong incidence of patent thickets and cross-licensing. This example shows that processes of strongly cumulative innovation can occur also in “discrete” technological fields. On the other hand, also in complex technology fields there are inventions that can individually be commercialized. For this reason, it is important to directly identify cumulative technologies, and to assess to what respect technological classification is able to capture the effects of cumulativeness.

order to capture differences in the significance and social value of single inventions relating to a cumulative research effort, we thus believe that it is necessary to allow for aspects of social value other than direct measures of impact.

Second, in order to identify cumulativeness, we introduce a sample of patents that are declared essential for technological standards. This sample reveals the effects of cumulativeness, as standardization is a pure case of cumulative innovation. We will compare a sample of (complex) patents declared as essential to technological standards with a control sample of patents from exactly the same (complex) technology classes, and another control sample of patents classified as discrete. This methodology allows us to establish whether particularities of patents classified in "complex" technology classes are really due to cumulativeness, and to disentangle the effects of cumulativeness from the technological class a patent belongs to.

We now turn to a description of the construction of the database and provide descriptive statistics for the various samples.

3. Data and Descriptive statistics

3.1 Construction of the samples and variables

Our objective is to analyze the way cumulativeness impacts the link between private and social value of patents. As discussed, we make use of two different strategies in order to identify cumulative innovation: first, we use data on patents essential for technological standards as a pure case of cumulative innovation. Second, we will use a sample of random patents classified in the same technological classes as the essential patents. These technological classes are consistently classified as "complex" classes in the relevant literature.

As data are most constrained for standard-essential patents, we first constituted a database of US patents that are essential to technological standards (Sample 1). This database is derived from patent disclosures at 8 standard setting organizations (SSOs) collected by Rysman and Simcoe[19] and from the websites of seven different patent pools (lists of SSOs

[19] Data available online at http://www.ssopatents.org/

and patent pools can be found in the appendix 3). It comprises overall 3343 essential patents[20].

By merging these patent lists with the NBER patent database, we inform the technology classes of 3128 patents and verify that the patents in our database cover technology classes that are classified as "complex" according to previous literature[21]. The concrete classification of technological classes into complex or discrete is still subject to debate. In our analysis, we will concentrate on clear cut cases of classes classified as complex or discrete according to several methodologies[22]. Details on our selection of classes can be found in appendix 4.

Based on the remaining patents, we construct a sample of siblings. These are US patents with the same application year and the same technology class randomly chosen from the NBER patent database. This second sample is what we will call in the following the group of complex, non-essential patents (Sample 2).

Finally, we build up a third sample of discrete patents (Sample 3). These are patents with the same application years as the patents in the other two samples, randomly chosen from a large range of discrete technology classes in the NBER patent database. The detailed, three-digit technology classes of both the complex and the discrete patent samples can be consulted in appendix.

Overall, we have 9255 patent observations. The NBER patent database yields information on citation flows and other important variables. We inform the number of *forward citations* (including and excluding self-citations), *backward citations* as well as the *generality* and *originality* indice**s**, both building upon citation data. We furthermore retrieve the number of *claims*, the *application year* and the *grant year*. We complete this information on patents using the website of the European Patent Office www.espacenet.com, where we retrieve the *size of the patent families* and indications on *renewals*.

Finally, using the Stanford IP litigation database (www.lexmachina.org), we generate a dummy variable - *litigated* - which gives 1 if the patent has been cited in at least one law suit in the database.

[20] 993 of these patents are part of a patent pool
[21] See von Harhoff et al. (2008) or Cohen et al. (2000)

[22] For instance, we rely upon the classifications used by von Graevenitz et al. (2009) and Cohen et al. (2000)

3.2 Descriptive statistics

In this section, we will use the comprehensive database to provide first descriptive statistics. In a first step, we will provide statistics on the average scores of indicators in the different samples (Table 2). While these statistics do not inform about the linkages between indicators, they corroborate several arguments on factors affecting the performance of single indicators in the comparison between discrete and cumulative innovation. For instance, we confirm earlier findings that citation rates are higher in complex technology classes and that patent families are larger in discrete technology classes: both backward and forward cite rates are significantly higher in Samples 1 and 2 than in Sample 3 whereas the scores for claims are not significantly different, and family size is much bigger in Sample 3 than in Sample 2. These differences of indicator levels in the different samples provide a further justification for our use of composite indicators to measure social value.

Regarding measures of private value, we confirm previous findings that the litigation rate is indeed higher in complex than in discrete industries (1.4 compared to 1 %)[23]. Furthermore, higher renewal rates in Samples 1 and 2 provide further evidence that less patents are of low value to their owners in complex technologies. Essential patents in Sample 1 are clearly found to be of a higher value to their owners, as indicated by much higher renewal and litigation rates.

Patents in Sample 1 score high on all the quality indicators and on renewal and litigation rate. This provides evidence that we are confronted with a selection effect: essential patents are not only more strongly cumulative, but also more valuable than average patents from their technological field. This bias can result from the fact that standard setting organizations often choose between different technological options and select the best technologies for inclusion into the standard. In the remainder of the analysis, we will have to control for this selection effect. We want to make sure that our findings on the link between private and social value in the sample of essential patents can be attributed to the strongly cumulative nature of these patents, and not to their high private and social value.

[23] This could hint to the fact that patents are indeed used in a slightly more “litigious” way in complex industries, and corroborates the argument that patents generate value in a different way from complex to discrete technological fields.

	Complete sample		**Sample 1** : Essential, very cumulative patents		**Sample 2** : Complex technology classes		**Sample 3** : Discrete technology classes	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Allnscites	23,35	42,76	40,15	57,86	20,93	36,66	8,58	15,42
Backward citations	9,30	14,12	11,72	16,18	8,87	15,38	7,28	9,67
Claims	16,85	15,09	19,66	17,54	15,77	12,92	15,19	14,07
Family size	15,66	46,33	24,75	62,67	6,51	17,88	13,64	40,15
Generality	0,35	0,37	0,43	0,35	0,39	0,37	0,22	0,34
Originality	0,23	0,24	0,25	0,22	0,26	0,25	0,14	0,22
Renewal at 8	0,73	0,44	0,95	0,21	0,73	0,44	0,59	0,49
Renewal at 12	0,57	0,50	0,92	0,27	0,55	0,50	0,37	0,48
Litigated	0,03	0,17	0,07	0,25	0,01	0,12	0,01	0,10

Table 2: Descriptive statistics of indicators

4. The quality indicators relevant for different types of technologies: the principal factor analysis

The aim of this part is to compare the consistency of indicators among the three different samples of patents using factor analysis. Factor analysis is a way to relate common variability among observed variables to a smaller number of underlying variables, called factors. Factor analysis estimates how much of the variability of the observed variables is due to common underlying factors. Thus, the factor analysis uses a large number of observations and reveals common patterns underlying the variables[24]. In this part we will use the factor analysis for our three samples: Sample 1 (essential, very cumulative patents), Sample 2 (complex technology classes) and Sample 3 (discrete technology classes). The objective is to study the consistency of the different indicators and to analyze if a common pattern exists among the samples.

We first want to make sure that our samples are comparable to those used in earlier analyses, and especially Lanjouw and Schankerman (2004). We therefore reproduce the earlier methodology and run a factor analysis on the four indicators most frequently used to assess the social value of a patent, namely the number of forward citations, the number of claims, the number of backward citations and the family size of the patent. We only make the

[24] In economics, factor analysis is used when capturing a common phenomenon is more interesting than analyzing individual variables. Lanjouw and Schankerman (2004) first used the principal factor analysis to identify an overall patent "quality" factor through four indicators.

comparison for Samples 2 and 3. Our results on this first factor analysis (presented in annex 1) are very close to the previous results using the same methodology. We highlight that the impact of forward citations on the common factor 1 is more important in Sample 3 than in Sample 2. Inversely, the impact of the number of claims is more important in Sample 2. We can also highlight that the common variability explained by factor 1 is less important in Sample 2.

We then implement our methodological innovations discussed above. First, we introduce our Sample 1 of essential patents, and second we include two additional indicators: the originality and the generality of the patent. The generality and originality, measured by the number of forward or backward citations between the patent and patents from other technological classes, indicate the patents' interest for broader technological applications (Hall et al., 2001). We do not restrict the number of common factors in order to allow for various aspects of the social value of patents. The notion of the social value of a patent indeed incorporates various complementary aspects, such as the contribution of an invention to social welfare, or the inventive step of a patented invention with respect to the state of the art. The following table summarizes the factor loadings for each sample.

	Sample 1 : Essential, very cumulative patents		**Sample 2** : Complex technology classes		**Sample 3** : Discrete technology classes	
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
Variance	0.47470	0.28419	0.26113	0.24636	0.48807	0.24936
Forward citations	0.2139	0.3903	0.3029	0.1377	0.4532	0.0021
Backward citations	-0.0722	0.0685	0.4036	-0.0143	0.3549	0.0762
Claims	0.0563	0.3745	0.4197	0.0469	0.2383	-0.0049
Originality	0.4441	0.0759	-0.0286	0.3467	-0.0794	0.3629
Generality	0.3828	0.1426	0.1113	0.3276	0.0370	0.3662
Family size	-0.0677	0.1463	0.2102	0.0289	0.4174	-0.0950
Number of observations	3191		3004		3139	

Table 3: Loadings factor analysis six indicators

Table 3 highlights that there are two main factors underlying these indicators. A first factor is mainly correlated to the number of forward citations, claims and to some extent backward citations and family size. This first factor has already been discussed in the literature (Lanjouw and Schankerman, 2004) and named "quality". In order to reflect the idea that these indicators measure the social impact of the underlying invention, we will call this factor "social value – impact". Table 3 also stresses the existence of a second factor, having an important impact on the indicators' common variability in all the samples. This second factor is mainly linked to the generality and the originality of the patent. In samples 1 and 2, this second factor also has significant loadings on the citation indicators. A plausible interpretation would be that this factor discriminates between fundamental and incremental innovations; which could be the reason why it is particularly linked to the generality and originality of the patent but also with the number of citations in the case of complex technologies. Trajtenberg et al. (1997) have examined the generality and originality indices and argue that these indicators measure the "basicness" of a patent. In order to refer to this concept, we will speak of "social value – basicness". For the sample of essential patents, the common variability of social value indicators is mainly driven by the social value – basicness factor.

This result implies that especially in the case of very cumulative innovation, it is important to take various aspects of social value into account. As we have argued above, when innovation is cumulative, it is unclear whether it is possible to assess the social value of patents in terms of impact. The idea of cumulativeness implies that not each single invention, but only all cumulative inventions taken together have an impact. The result on the social value -- basicness factor confirms that there exist other aspects to rank the social value of cumulative patents. The aspect highlighted by our basicness factor is the place of an invention in the innovation chain discriminating between some inventions being fundamental, and others being narrow and incremental contributions.

In spite of the presence of a second factor that is especially important in samples of cumulative patents, we identify a social value - impact factor that is roughly consistent across the samples. In all three samples, this factor is driven by a positive correlation between forward citations, claims and family size. Nevertheless, the loadings of indicators are slightly different between complex and discrete technologies. The number of claims seems to have more impact than the number of forward citations on the social value - impact factor for Sample 2. It is exactly the opposite in Sample 3, where the most important indicator is the number of forward citations. Backward citations are important and stable components of the social value – impact factor for both Samples 2 and 3, but do not have any importance for Sample 1 of essential, highly cumulative patents.

Another important difference is the variance explained by the social value - impact factor between the complex and discrete sample. Indeed, we can underline that this factor explains almost fifty percent of the common variability of the indicators for Sample 3. However, in the Sample 1 and 2, this factor only explains one fourth of the common variability of the indicators.

For the social value - basicness factor, we argue that it captures the fundamentality of the patent, i.e. its place in a chain of cumulative innovation. This factor is orthogonal to the impact factor of the individual patent, and takes into account the relationship between this patent and complementary patents. This factor is thus useful for discriminating between fundamental, early-stage patents, and incremental patents in a later stage of a cumulative innovation effort. Consistently with this interpretation, this factor is more important in the samples of complex technology patents, and especially in the sample of strongly cumulative essential patents. Indeed, the social value - basicness factor captures almost 50 % of the common variability of patent indicators in this particular sample of very cumulative patents. We use data on the timing of declaration or introduction of patents into standard setting organizations and patent pools to corroborate our interpretation. The results are presented in table 4 (appendix 4). They show that both factors are related to being a founding patent. The results stress that being a founding patent of a pool or being declared early in a standardization project is significantly linked to a high score on the social value - basicness factor[25]. The social value - impact factor is also significantly associated with the likelihood of being a founding patent.

To sum up our main conclusions, we can say that the factor analysis underlines the existence of two factors driving the common variability of the indicators. The first one, mainly linked to the traditional indicators of “quality”, has already been studied in the literature. The second one is mainly driven by the generality and originality of the patent. We call it the social value - basicness factor and give some evidence corroborating our interpretation. For Sample 1, this basicness factor explains almost half of the common variability of the indicators. This is the first time that these different aspects of the social value of patents are discussed and empirically related to the private value of patents. While in the case of discrete technology patents (Sample 3), one single factor seems sufficient to capture a large part of the common variability of indicators of social value, in the case of cumulative innovation, allowing for our second factor strongly increases the part of the variability of the indicators captured by the underlying factors.

The traditional “quality” factor, which we call social value – impact factor, seems to remain stable (with some minor changes on claims and forward citations) across our three different samples except for the importance of the backward citations. Indeed, there is a stable covariance of forward citations, claims and family size across the samples. Nevertheless, this

[25] This confirms our interpretation that this factor discriminates between fundamental and incremental innovations.

factor captures a lower part of the common variability of indicators in Samples 1 and 2. This factor is however not less important in Sample 1 than in Sample 2. If there is thus a difference in the capacity of patent indicators to measure the social value of patents, this difference affects only the comparison of complex and discrete technology patents. The patent indicators do not seem to perform worse in capturing the social value in the case of the very cumulative essential patents.

In the next section, we will look at the ability of these factors to predict the private value of the patents. In order to assess the private value of a patent, we will use data on renewals and litigations. To take into account the instability of backward citations in the social value - impact factor, we will use a common factor compound of forward citations, claims and family size. Results for the single indicators can be consulted in the appendix.

5. The link between private and social value of patents in discrete and cumulative innovation

As discussed in part I, we expect that the link between indicators of private and social value of patents is weakened when innovation is cumulative. We will analyze whether this link is weaker for random patents in complex technology classes than for patents in discrete technology classes, and whether this link is weaker for essential, very cumulative patents than for patents randomly drawn from the same (complex) technology classes.

Specifically, we will estimate the private value of patents in an ordered logistic regression estimation of patent renewals 4, 8 and 12 years after grant. First proposed by Lanjouw et al. (1998), patent renewals are by now a well-established indicator of the private value of a patent (Bessen, 2006). As every renewal is costly and the cost of patent renewal is increasing over time, patent renewal decisions reveal the willingness to pay of the patent holder for patent protection. Comparing samples of complex and discrete technology patents, we will test whether the common social value factors are less explanatory of patent value in complex technologies. We also analyze whether the mere fact of holding a patent is more valuable in cumulative innovation, i.e. whether patents in cumulative innovation have a higher private value than patents in discrete technologies of the same social value[26].

[26] See for instance Liu et al. (2008)

We have two means to test for the effects of cumulativeness. First, we test for the effect of a patent being classified in a "complex" rather than a "discrete" technology class. Complex technologies are thought of in the literature as being characterized by a more cumulative type of innovation. Second, we use a sample of patents declared essential for standards. As explained above, standardization is a procedure to ensure compatibility between complementary technologies and therefore a perfect example of cumulative innovation. We have thus argued that if cumulative innovation weakens the link between patent quality and patent value, this should clearly be seen in the case of essential patents.

We thus estimate the following baseline equation:

$$V = \alpha \cdot Q + C + \delta \cdot X + \varepsilon \qquad \textbf{(1)}$$

where V represents private value, measured through an ordered logistic regression of the probability of patent renewal. Q represents social value, measured by the two different social value factors established in part III.1. X is a vector of control variables, including application year and assignee dummies. These control variables have been chosen in agreement with the literature on the subject[27]. C is a constant and ε is a stochastic error term.

We introduce dummies for complex technologies and essential patents. Both dummies are interacted with the social value of patents.

$$\boldsymbol{V = \alpha \cdot Q + [\beta \cdot Pc \ + \gamma \cdot Pc \times Q] + [\beta' \cdot Ps \ + \gamma' \cdot Ps \times Q] + \delta \cdot X + C + \ \varepsilon} \qquad \textbf{(2)}$$

Hypothesis 1:

> $\boldsymbol{\beta} > 0$ and $\boldsymbol{\beta'} > 0$, there is a premium for patents in cumulative innovation, therefore patents in complex technologies (respectively essential patents) are more valuable to their owners than patents of the same social value in discrete innovation. This hypothesis predicts that cumulativeness has an impact on the level of private value of patents.

Hypothesis 2:

> $\boldsymbol{\gamma} < 0$ and $\boldsymbol{\gamma'} < 0$, social value has a lower impact on private value in cumulative innovation. This hypothesis predicts that cumulativeness has an impact on the link between private and social value.

[27] see for instance Hall et al. (2001) on the variables that have an impact on the number of citations

	Ordered logistic Regression renewals		Ordered logistic Regression renewals	
	Coef.	Odds ratios	Coef.	Odds ratios
Impact factor	1.07511*** (0.267)	2.930*** (0.781)	1.09445*** (0.273)	2.988*** (0.814)
Basicness factor			-0.01812 (0.157)	0.982 (0.154)
Dummy essential	1.7190671*** (0.287)	5.579*** (1.604)	1.74413*** (0.342)	5.721*** (1.956)
Dummy complex	0.47798*** (0.133)	1.613*** (0.214)	0.55548*** (0.144)	1.743*** (0.251)
Interaction Impact_essential	-1.46111** (0.563)	0.232** (0.131)	-1.45623* (0.615)	0.233** (0.143)
Interaction Impact_complex	0.57896 (0.363)	1.784 (0.649)	0.69004 (0.376)	1.994 (0.749)
Interaction Basicness_essential			-0.31799 (0.743)	0.727 (0.540)
Interaction Basicness_complex			-0.27421 (0.238)	0.760 (0.181)
Grant year	-0.05839 (0.060)	0.943 (0.057)	-0.06079 (0.060)	0.941 (0.057)
Control appyear dummy	Y		Y	
Control assignee dummy	Y		Y	
Number of obs	1637		1637	
Log pseudolikelihood	-1753.59		-1751.81	
Wald chi2	290.41		288.62	
Prob > chi2	0.0000		0.0000	
Pseudo R2	0.0988		0.0998	

Table 4: The link between quality and value for cumulative and discrete innovation

Table 4 allows underlining a couple of results. First of all, only the social value – impact factor is significant for the definition of the private value of a patent. The coefficient for the social value - impact factor is positive and significant for our two models. The link between private value and a compound factor of traditional “quality” indicators is verified in our case.

On the other hand, even though important for establishing the social value of a patent, the social value – basicness factor does not have any significant effect on the private value of patents in any of the samples. Fundamental patents are no more valuable to their owners than incremental patents of the same social value – impact.

Hypothesis 1 is verified, there is a premium for patents in cumulative innovations. Thus, a patent in cumulative innovation is more valuable to its owner than a patent of the same social value in discrete technologies. This result is confirmed for both patents classified in complex technology classes, and for very cumulative essential patents. This finding relates to earlier research finding that patents that are part of sequential innovation are more valuable to their holders (Liu et al., 2008). Furthermore, we can infer from this result that a patent in cumulative innovation generates value for its owner even when it has a very low social value. This is in line with the theoretical argument that holding a patent in cumulative innovation is valuable per se, as patents can be used e.g. as mass of negotiation.

Hypothesis 2 is verified only for very cumulative patents. The coefficient on the interaction term *interaction_impact_essential* is negative and significant. Therefore, the social value - impact is significantly less important for the definition of private patent value for cumulative innovation (i.e. the link between private and social value is less obvious for this type of very cumulative innovation). But hypothesis 2 is not verified for Sample 2 of random “complex” technology class patents. Therefore, the social value of a patent is not less important for determining the private value of patents in complex than in discrete technology classes. This result casts doubts on the hypothesis that the link between private and social value of patents is weaker in whole “complex” technology classes than for patents classified in discrete technology classes.

The social value - impact factor predicts renewal in Samples 2 and 3, but not in our Sample 1 of essential, very cumulative patents. We verify that this is not due to a selection effect. Indeed, one could argue that patent indicators are less informative of patent value in a sample of essential patents, as all these patents are selected and their private and social value is above average[28]. There is no evidence for non-linear effects of social on private patent value in any sample, and our results hold under all the different control strategies[29]. As we can rule out that our results are driven by a selection effect, we argue that it is clearly cumulativeness that alters the way how patents generate value. Nevertheless, this

[28] We control for selection effects by excluding all patents from the analysis that have never been renewed, by restricting the samples to patents that have been litigated, by dropping all patents from the sample that have a social value – impact factor score below average, and by introducing the square of the social value factors to control for non-linear effects.
[29] The results are available upon request from the authors.

cumulativeness is rather unrelated to technological classes, as Sample 2 does not exhibit any weakened link between private and social value of patents.

Table 7 (appendix 5) allows refining the previous results. We run the same regression as in Table 4 for each patent indicator individually. For model 1, we use in the same regression all the indicators together as explanatory variables. The coefficients therefore allow assessing the indicators' impact holding other patent characteristics constant. Model 2 reports the coefficients for each indicator used individually as explanatory variable. In order to check the sensitivity of our results to our indicator of private patent value, we also introduce patent litigation as an alternative indicator (Lanjouw and Schankerman, 1999).

Table 7 confirms that indicators of social value, especially forward citations, claims and family size are good predictors of the private value of patents (measured by litigation or renewal) for discrete and complex non-essential technologies. The main result is that no indicator of social value predicts the private value of essential, very cumulative, patents. This is in line with our hypothesis that cumulativeness disrupts the link between private and social value due to the different use of patents in the two types of innovation.

However, the traditional indicators of "patent quality" are significant predictors of patent value for other patents in the same technology classes. While cumulativeness therefore has an impact on the link between patent quality and value, the real difference is not between complex and discrete technological classes, but between the narrow sample of very cumulative essential patents and the remainder of the patent population.

6. Conclusion: Implications for policy and research methodology

We have highlighted two aspects of social value of patents that can be related to two common factors driving the common variability of measurable patent characteristics. Besides a social value – impact factor, mainly related to traditional indicators of patent "quality", we evidence a social value – basicness factor, which is particularly predominant in the case of very cumulative innovation. This is the first analysis to discuss and evidence the importance of this second aspect of social value of patents.

We have demonstrated a very significant and robust relationship between the social value – impact factor and the private value of patents classified in discrete and complex technology classes. Traditional “quality” indicators work well in predicting the private value of patents. Nevertheless, this robust relationship completely disappears in highly cumulative innovation, as demonstrated using a sample of patents declared essential to technological standards. While these patents have both a higher social and private value than control patents, none of the two aspects of social value plays any role for explaining differences in private value inside the sample of essential, highly cumulative patents. Nevertheless, these results cannot be generalized to whole “complex” technological classes. This finding casts doubts on the hypothesis that theses classes are generally dominated by cumulative innovation.

On the one hand, we have found that in the case of highly cumulative innovation, the private value of each patent is generally high, but independent of measures of social value. This has strong implications for patent filing incentives and innovation strategies. If there is no link between the private value of a patent and the social value of the underlying invention, innovators have incentives not to pursue social value, as long as they can achieve patentability. This finding helps to revisit the patent portfolio theory (Parchomovsky and Wagner, 2005), according to which holding patents is valuable as such, independently of the value of the underlying inventions. We thus provide support to those who see the surge in patenting in highly cumulative technological sectors with some worries.

In order for the patent system to provide socially efficient innovation incentives, there must be some link between the private and social value of patents. We have discussed and shown in the data that the notion of social value is a concept which incorporates different aspects. In the case of very cumulative innovation, the traditional aspect regarding the impact of a single invention seems to be less relevant than another aspect, reflecting the basicness of the invention in the cumulative research effort. We have shown that there are indicators that can be used to measure this basicness, but that they do not display any significant link to measures of private value. This absence of link between private and social value could explain the importance of strategic patenting and litigation surrounding cumulative innovation, such as ICT standardization. This is especially worrying, as many of the most important current technological evolutions are characterized by strong cumulativeness.

On the other hand, our results suggest that the link between private and social value is robust in the remainder of the patent population and stable across technology classes. Indeed, our Sample 2 of complex technology patents drawn from exactly the same classes as the essential patents in Sample 1 does not exhibit a weakened link between private and social value. This latter finding is important for appreciating the implications for research methodology. Indeed, we find no evidence that indicators of social value of patents are less informative in complex than in discrete technological classes. In spite of the lower common variability of indicators, the social value factors predict renewal decisions and litigation even more accurately for (randomly chosen) “complex” technology patents in Sample 2 than for “discrete” technology patents in Sample 3. This suggests that the link between private and social value is affected only in narrow, yet highly relevant technological fields. Technological classification of patents seems unable to capture this phenomenon.

Chapter II : The Strategies of Patent Introduction into Patent Pools

Les stratégies d'introduction de brevets dans les pools de brevets

Cet article analyse les différentes stratégies des firmes d'introduire des brevets dans des pools de brevets. Nous conduisons une analyse empirique de 1.337 brevets américains introduits dans 7 pools différents. L'analyse montre que parmi les brevets inclus dans les pools, les brevets qui appartiennent aux membres fondateurs du pool sont plus étroits, plus incrémentaux et moins cités. A tout âge du pool, les anciens membres introduisent des brevets plus étroits et moins significatifs que les nouveaux entrants. Ces résultats indiquent qu'il y a un avantage d'insider pour les membres du pool, qui peut être expliqué à la fois par un pouvoir accru de négociation et par l'asymétrie d'information. Nous apportons des éléments empiriques qui corroborent notamment l'hypothèse d'un effet d'apprentissage. En utilisant un nouvel indicateur, nous trouvons que des membres expérimentés du pool introduisent des brevets mieux ciblés sur le standard sous-jacent au pool.

1. Introduction

Patent pools are agreements between different patent holders to offer joint licenses for a bundle of patents. Since the successful launch of the MPEG2[30] and DVD patent pools in 1997 and 1999, pools have evolved with impressive speed. Today, patent pools are a phenomenon of increasing and undeniable importance in Information and Communication Technologies (ICT). Modern mobile phones, DVD or mp3 players, receivers for digital TV—all these high tech consumer goods use technology licensed out through patent pools. The value of products produced under pool licenses and sold on the US market exceeded US $100 billion annually in 2003 (Clarkson, 2004)[31].

Most contemporary patent pools are related to technological standards. The importance of patent pools in ICT results from the fact that technological standards incorporate an increasing number of technologies protected by patents (Shapiro, 2001, Bekkers and West, 2009). Patents that are essential to the same standard are strictly complementary, but can be held by many different firms. This is the constellation in which patent pools are most likely to be efficiency-enhancing (Lerner and Tirole, 2004). On the one hand, patent pools indeed play a beneficial role in standardized technologies. First, by bundling patents, they reduce the transaction costs by cutting down the number of licenses needed to comply with the standard. Second, pools reduce the multiple marginalization problem[32]. This problem arises when different firms have market power over complementary inputs (such as different patents necessary for complying with the same standard), and the firms fix prices independently of each other. On the other hand, patent pools have an effect on the returns on essential patents, and can potentially exacerbate opportunistic patenting strategies regarding standard-essential technology (Bekkers and West, 2009; Berger et al., 2012).

Even though practitioners report that opportunistic strategies of patent introduction are among the major threats to current patent pools (Peters, 2011), there is to date little empirical analysis of the patenting strategies around patent pools. The purpose of this paper is to fill this gap and to analyze the patterns of patent introduction into major contemporary pools. We analyze the link between pool membership and the technological characteristics of the

[30] MPEG2 is a data compression technology of moving pictures used in digital television, Internet streaming, DVDs among other uses.

[31] More recent estimations made by the Fuji Chimera Research Institute indicate that the importance of pools keeps increasing, the amount of royalties collected by the MPEG2 and DVD patent pools being multiplied by 4 between 2003 and 2008, reaching an amount of 7.8 billion US dollar per year (Wajima et al., 2010).

[32] This problem was first analyzed by Cournot (1838) as “the exercise of market power at successive vertical layers in a supply chain”.

patents that are introduced. For instance, we compare patents introduced by incumbent members and entrants regarding their breadth and generality, as well as their significance and match with the standard. We have produced a unique dataset on the timing of patent introduction into several of the most important pools that currently exist. Furthermore, we make use of technical documents to construct a novel indicator for the technological focus of a patent on the technology underlying the pool.

We find that patents introduced are increasingly narrow, incremental and insignificant over time. Especially incumbent members introduce patents that are narrower and less significant than patents introduced at the same time by entrant companies. As a result, the founding members of a pool hold a broad majority of the patents currently included in the pools in our sample, but their patents are narrower, more incremental and less significant on average than the patents held by companies that joined the pool at some time after pool creation. We also introduce a novel indicator for the match of a patent with the standard underlying the patent pool, and show that insiders introduce patents that are essential to broader parts of the standard. The pool founding members are those companies that have developed the earliest essential patents and are hence more central in the development of the standard. But the stronger focus of their patents could also result from better access to information on the criteria of essentiality, or from the fact that the development of incremental standard relevant technology is streamlined towards the technological inputs available from the pool.

The remainder of this paper is organized as follows. Section 2 presents a review of the economic literature on pools and discusses main institutional features of contemporary ICT pools. Section 3 presents the methodology and provides a quick overview of the data and indicators used in this analysis. Section 4 presents our main empirical results, and discusses their implications. Section 5 concludes and sketches further research opportunities.

2. Analytical framework

2.1 Economic literature on patent pools

There is now an increasing body of research on the effect of patent pools on innovation incentives[33]. This effect strongly depends upon how patent pools affect the return that patents generate for their owners. As patent pools are voluntary agreements between patent holders, it can be assumed that patent pool creation increases expected revenue of at least some patent holders (Lerner and Tirole, 2004).

One important and widely recognized benefit of patent pools is that they mitigate the costs of multiple marginalization. The creation of a patent pool is beneficial for patent holders, as it efficiently reduces the overall licensing cost to the monopoly price (Shapiro 2001). Patent holders however benefit most from patent pool creation if they stay out of the pool. Indeed, the collective effort of pool members to reduce licensing costs results in a higher demand for all complementary patents, including the patents held by the outsiders. By contrast to pool members, outsiders can react to this increase in demand by raising the prices for their own patents (Aoki and Nagaoka, 2004). From this point of view, it is hard to understand why many companies join existing patent pools.

In other models of the effect of patent pools on innovation, it is assumed that the value of a patent is higher if it is included into a pool than if it stays out (Dequiedt and Versaevel, 2012). Empirical evidence indeed suggests that the value of a patent increases with its introduction into a patent pool (Delcamp, 2011-1). This effect could for instance be explained by lower transaction costs for licensing, by a signal strengthening the presumption of essentiality, or by facilitated patent enforcement (Delcamp, 2011-2, Choi 2011). We would then expect that outsiders are willing to integrate existing pools. Dequiedt and Versaevel (2012) assume that in order to do so, outsiders must negotiate their entry with incumbent members, who dispose of bargaining power and can extract the additional benefit of pool membership from new joiners. The positive effect of patent pools on patent value thus only benefits the founding members of a pool. This reward for founding members in turn spurs patent races, and leads companies to anticipate their R&D investments.

In practice, the incentives to join patent pools depend upon the characteristics of the respective pool, firms and patents. For instance, Layne-Farrar and Lerner (2011) find that

[33] Cf. Lerner and Tirole (2004), Dequiedt and Versaevel (2007), Llanes and Trento (2010), Lampe and Moser (2010), Lampe and Moser (2011), Joshi and Nerkal (2011a)

holders of relatively more valuable patents refrain from joining patent pools practicing royalty sharing rules based solely upon the number of patents. Accordingly, Layne-Farrar (2011) finds that pool patents are generally less significant than other patents that are essential to standards. This finding conflicts with other investigations revealing that pools tend to include better patents than appropriate control patents (Lerner et al., 2007; Delcamp, 2011-1; Joshi and Nerkar, 2011-2).

While Layne-Farrar and Lerner (2011) investigate the binary decision of firms whether to join a pool or not, Nagaoka et al. (2009) document a continuous growth of the number of patents included in patent pools over time. They find strong evidence for the hypothesis of a strategic increase of patent portfolios, as around 40% of the essential US patents in the pools for MPEG2 and DVD standards have been obtained through continuations. The authors also focus on whether a founding member of a pool can obtain more essential patents by using these practices. They find that to the contrary firms with pioneering patents tend to have a smaller number of essential patents obtained through continuations.

2.2 Stylized facts

In order to analyze the incentives and capacities of pool members and outsiders to file and introduce patents, it is important to present two main features of the institutional setting of contemporary patent pools. These features are the rules on revenue sharing between patent pool members and rules governing the inclusion of patents into pools.

2.2.1 Revenue-sharing rules

All pools that collect royalties have rules on how these royalties are shared between members. Pool members are free to agree on their preferred sharing rule. Layne-Farrar and Lerner (2011) identify two main types of sharing rules: numeric proportional rules and value added rules. Both rules provide important incentives to firms for increasing their share of patents in the pool.

The numeric proportional rule consists of dividing earnings proportional to the number of essential patents in the pool. All the pools administered by MPEG LA[34] use this revenue

[34] MPEG Licensing Association is one of the currently most important pool administrators (together with Via Licensing and Sisvel). There are currently 8 patent pools administered by MPEG LA, including very important pools such as MPEG2.

sharing rule (Layne-Farrar & Lerner, 2011). The numeric proportional rule has a direct incidence on the incentives to introduce a high number of patents.

The value added rule exists in several variants. The variant practiced by the DVD6C patent pool is a royalty sharing rule based on the number of patents weighted by determinants such as the age of the patents, the number of claims, the number of times the patents are infringed, and the part of the standard these patents are essential for (Layne-Farrar & Lerner, 2011). Even though the value added rule weights the number of patents by some indicators of patent quality, it still provides incentives to firms to increase their share of patents in the pool, even if the additions are of lower quality[35].

2.2.2 The rules governing inclusion of patents into patent pools

In order to qualify for introduction into a pool, a patent has to be essential to the underlying standard. The claim of essentiality of the patents is usually assessed by a third party evaluator. There are several points to highlight on this essentiality criteria.

First, the criteria of essentiality are not always exactly the same and pools have some discretion in defining their criteria[36]. Furthermore, not all pools force members to consult the expert[37]. Finally, it is difficult to ascertain to what degree pool members can influence the outcome of the patent evaluation. Patent evaluators are appointed by the pool administrator and paid by the patent holders. In several cases of litigation, licensees have accused patent evaluators of being overly lax in their evaluation of allegedly essential patents.[38]

Most importantly, the criteria of the essentiality evaluation do not restrict the patent propensity on essential technology. Essential patents can still be of low technological or economic value. For instance, owners of an essential technology can often choose to protect it by one large or several narrow patents. Furthermore, holders of essential technology can

[35] The business review letter of the DVD6C pool states: “although the formula weights the patent count with other factors, each Licensor will benefit monetarily from the exclusion of other Licensors’ non-‘essential’ patents and accordingly has a strong incentive to encourage the expert to review other Licensors' patents critically’ ”.

[36] For instance, the MPEG 2 pool uses the technical essentiality criteria (no alternative available) whereas the DVD 6C pool uses the economic feasibility criteria (no economically feasible alternative)

[37] For instance, the MPEG 2 pool stipulates: “The licensors are bound by the expert’s opinion. However, they need not consult the expert if they agree unanimously in good faith that a submitted patent is an essential patent or that a portfolio patent is not essential”

[38] This claim is raised as patent misuse defence in many patent infringement cases, e.g. by disc replicator ODS in its litigation MPEGLA over the MPEG2 patent pool; Landgericht Düsseldorf Urteil vom 30. November 2006, Az. 4b O 346/05; V. b) cc)

patent even incremental inventions relating to a standard, which they would normally not have patented.

We have seen that the royalty sharing rules induce incentives for firms to increase their number of essential patents included in the pool. We have also discussed that essentiality evaluation by patent pool experts does not rule out the possibility of opportunistic patent introductions into pools. For instance, companies can file more and narrower patents, and they can patent even very incremental inventions relating to the technology covered by the pool. We will therefore analyze in the remainder of this article the width, generality and significance of the patents introduced into patent pools by the various companies.

3. Methodology

We analyze the characteristics of pool patents with respect to the owners of the patent and the timing of their introduction. In particular, we compare the characteristics of introduced patents according to whether the patent holder was already a pool member before inclusion of this patent.

3.1 Data

We have produced a unique database of 7 important patent pools: DVD6C, MPEG2, MPEG4 Systems, MPEG4 Visuals, AVC H/264, IEEE 1394 and DVB-T[39]. The institutional setting of the pools is very similar. In order to avoid allegations of anti-competitive conduct, all these pools adopted an institutional framework similar to the arrangements that had already been cleared as non-infringing. The seven patent pools provide us with 8,046 patent observations. A few patents are included in several pools; for our purpose the same patent in different pools is treated as a separate patent observation each time it appears. Furthermore patents sometimes change the designation by which they are identified on patent lists, expire or are retrieved. The 8,046 observations thus stand for around 5,000 patents that were included in the pool at the time of observation.

[39] DVD6C is one of the two patent pools licensing out patents essential for DVD specifications, MPEG2, MPEG4 Systems, MPEG4 Visuals and AVC H/264are patent pools including essential patents for coding standards issued by the Moving Pictures Expert Group, the IEEE 1394 patent pool covers wireless communication technology, and DVB-T is a patent pool for patents on Digital Video Broadcasting technology.

We retrieved the patent numbers and the name of patent holders from the lists available on the websites of the pools[40]. Using Internet Archives,[41] we checked when the patent first appeared on the list of pool patents. We call this the date of input. As the sites may be updated or the update be retrieved from the Archives after some delay, the date we identify as date of input may differ from the actual date of introduction by as much as a couple of months. Nevertheless, our method reliably identifies the order in which patents and thus firms are introduced into pools.

The patents in our sample are issued by all the major patent offices in the World. The highest number of observations are Japanese patents (1.878 observations), followed by the US patents (1.337 observations). In order to compare only what is comparable; we restrict our analysis to the 1.337 U.S. patent observations in our sample (we have 1.259 unique patents, as 44 patents are included in two, 13 patents in three and 3 patents in four patent pools). The majority of US patents in our sample have a Japanese priority application. Nevertheless, out of out 615 distinct patent families including US patents, 380 have a US priority. When a patent family includes patents from several countries, the US patent is in general the first patent of the family to be introduced into the pool. In only 29 cases, the Japanese patent has been introduced before the US patent (Appendix 1). This pattern is probably due to the fact that the essentiality evaluation is carried through by US experts and based upon the US patent. As our research focuses on the strategies of patent introduction into patent pools, US patents are thus the appropriate level of analysis.

Table 1 shows how these patents are distributed over the pools, and the shares of US patents introduced at the time when the pool was created (US founding patents), of patents introduced by founding members of the pool, and of patents introduced by companies that eventually joined. By matching the patent numbers with the National Bureau of Economic Research (NBER) database, we obtain a full range of information on the patents, and especially the number of claims, forward citations (forward cites count the number of times a patent is cited by ulterior patents), patent generality, technological class, and grant and application year. In order to deal with truncation problems and missing observations, we completed the dataset using the web service of the European Patent Office[42].

---

[40] www.mpegla.com (MPEG2, MPEG4 Systems, AVC, IEEE 1394), www.dvd6cla.com (DVD6C), www.sisvel.com (dvb-t)
[41] www.archive.org
[42] www.espacenet.com

	Founding members				Entrant companies		
	# of firms	# of US patents	# of US founding patents	Firms	# of firms	# of US patents	Firms
IEEE 1394	9	62	34	Apple, Canon, Compaq, Hitachi, Panasonic, Philips, STMicroelectronics, Sony, Toshiba	1	1	LG
DVD 6C	7	771	124	Hitachi, IBM, JVC, Mitsubishi, Panasonic, Toshiba, Warner	3	101	Samsung, Sanyo, Sharp
MPEG 2	7	65	39	Mitsubishi, Next Level System, Panasonic, Philips, Samsung, Scientific Atlanta, Sony	10	47	Alcatel, British Telecom, CIF Licensing, Canon, France Télécom, General Electric, General Instrument, JVC, Thomson, Toshiba
MPEG4 Systems	6	9	6	Apple, ETRI, France Télécom, Philips, Samsung, Sun Microsystems	0	0	
MPEG4 Visual	16	140	33	Canon, France Télécom, Fujitsu, General Electric, General Instrument, Hitachi, Microsoft, Mitsubishi, Panasonic, Pantech Curitel, Philips, Samsung, Sharp, Sony, Telenor, Toshiba	6	9	British Telecom, CIF Licensing, Competitive Technologies, LG, Sedna, Siemens
AVC H.264	9	75	28	France Télécom, Fujitsu, Microsoft, Mitsubishi, Panasonic, Philips, Sharp, Sony, Toshiba	11	53	Apple, Dolby, ETRI, Fraunhofer, LG, LSI, NTT, Samsung, Scientific Atlanta, Sedna, Siemens
DVB-T	4	5	5	France Télécom, JVC, Panasonic, Philips	0	0	

Table 1. Founding members and entrant companies by pool

We collect four important dates for each patent: application date, grant date, date of pool creation and date of introduction into the pool. From these dates are drawn our age variables. Patent age is the difference between today and the grant date, and Input age is the age of the pool at the time a patent was introduced, defined as the difference between date of input and pool creation date.

3.2 Indicators

The main purpose of our paper is to analyze strategies of patent introduction into patent pools.. We will focus upon the timing of introduction, and compare the characteristics of patents compared at different moments into the pool by incumbent pool members and new firms joining the pool. We characterize the patents through objective indicators commonly used in economic research. First, we use the number of claims. The number of claims is often used as an indicator of the patent breadth[43]. This view has been questioned by Allison et al. (2004), who relate the number of claims rather to the willingness to pay of the applicant. In any case, the number of claims exhibits a strong positive correlation with other indicators of patent significance, and is a valuable indicator of patent significance especially in the case of cumulative technologies (Chapter 1).

The second indicator we use is the generality index. Patent generality is defined as the dispersion of prior art over technology classes. If a patent cites prior art that is technologically very heterogeneous, it is more likely to protect a fundamental invention. (Trajtenberg et al, 1997)[44]. We furthermore use the number of forward cites, which is the most frequently used indicator of technological significance (Harhoff et al. 1997, Hall et al. 2001, Giummo 2003).[45.] We also compare patent strategies by providing statistics on the family size. Family size is a common indicator of the private value of a patent (Putnam, 1996), as the costs of filing increase with the number of countries in which the innovation is protected.

Finally, we construct a novel indicator for the focus of a patent on a standard. This indicator is based upon the breadth of the essentiality claim. As discussed earlier, the patent essentiality reports indicate the standard sections for which each patent is essential. We count the standard sections and correct by the median of patents in the same pool (respectively in the same licensing program for pools with several distinct licensing programs). Estimating the effects of patent pools on the breadth of the essentiality claim and controlling for the breadth of the patent itself should give a good indication of the patent's focus on the standard underlying the pool.

A list of all the variables used in this paper with some descriptive statistics can be found in Appendix 2. In the following table, we can see the correlations of the different indicators in our sample, as well as correlations of each indicator with the time of patent introduction into

[43] (e.g. Merges & Nelson 1990, Klemperer 1990, Reitzig 2004).

[44] In Chapter 1, we show that the generality index is an especially meaningful indicator in the context of essential patents.

[45] To exclude any bias and in line with most empirical research on patent quality, we exclude citations received by patents owned by the same firm; see also Hall et al. (2001)

the pool. Forward citations, the number of claims and the generality index display a significant positive correlation. These three indicators are significantly negatively correlated with the time of introduction: pools include increasingly narrow, incremental and insignificant patents. These patent indicators are however not significantly correlated with family size or with the scope of the essentiality claim. There is however a significant correlation between these two values, providing weak evidence that the private value of an essential patent is correlated with the breadth of the covered parts of the standard.

	Age_input	Allnscites	Claims	Genindex	Family
Allnscites	-0.312 (0.000)				
Number_claims	-0.059 (0.033)	0.108 (0.000)			
Genindex	-0.347 (0.000)	0.329 (0.000)	0.167 (0.000)		
Family_size	-0.017 (0.651)	-0.026 (0.501)	-0.035 (0.365)	-0.094 (0.021)	
Standard sections	0.050 (0.083)	-0.063 (0.031)	0.009 (0.752)	-0.014 (0.720)	0.296 (0.000)

Table 2. Correlation table, indicators

4. Empirical results

4.1 Descriptive analysis

In a first step, we compare patents introduced by founding members of a pool with patents introduced by companies. Table 3 shows that there is no significant difference in the age of pool patents of founding members and late joiners. The patents of founding members have on average not been granted before the patents of late joiners. On average, the pool patents have been granted more than 4 years before the official creation of the pool. But only 243 out of the 1059 pool patents held by founding members have been included in the pools since their creation, 816 patents have been added eventually. Among the 170 pool patents held by late joiners, 138 patents have been included when the company joined the pool, and 32 have been added eventually. Comparing the age of patents which the companies first introduced into the pool, we can see that the founding patents of the pool have been granted on average almost 8 years before the official launch of the pool, significantly earlier than the first patents that late joiners introduce into the pool. These findings are consistent with the hypothesis that the founding members of a pool are a coalition of the first companies to own patents qualifying for the pool[46]. These companies also account for the majority of patents eventually added.

		Age of patents	Age of first inputs
Late joiners	Mean	4.466	4.206
	Obs.	170	138
Founding members	Mean	4.421	7.891
	Obs.	1059	243
t-statistics	t	0.144	-9.487
	Pr(T < t)	0.557	0.0000
	Pr(T > t)	0.443	1.0000

Table 3. T-test patent age late joiners vs. founding members

When comparing the technical characteristics of the pool patents held by founding members and late joiners, we notice significant differences regarding almost all the indicators. The pool patents of late joiners are significantly more cited, have more claims, and are more general. These results confirm that founding members have pool patents of lower average[47].

[46] This pattern is consistent with the pool creation model of Dequiedt and Versaevel (2007), and is opposed to the model of Aoki and Nagaoka (2004).

[47] For an analysis of these differences inside the different pools, see Appendix 3

		Citations	Claims	Generality	Standard sections
Late joiners (0)	Mean Obs.	26.069 170	20.095 211	0.470 84	1.191 174
Founding members (1)	Mean Obs.	16.591 1059	14.913 1101	0.312 623	1.448 1037
t-statistics	t Pr(T < t) Pr(T > t)	3.925 1.0000 0.0000	4.327 1.0000 0.0000	3.759 0.9999 0.0001	-3.330 0.0004 0.9996

Table 4. T-test patent indicators late joiners vs. founding members

4.2 Estimation

We next compare the patent characteristics between patents introduced by incumbent members and by new entrants. We distinguish between three different constellations: a patent is a founding patent of a pool, a patent is introduced into an existing patent pool by an incumbent member, and a patent is introduced into an existing pool by a new entrant. We thus regress the patent characteristics on a dummy for founding patents, and a dummy for new entrants. We control for the age of the patent, the time of patent introduction and the fixed characteristics of the pool.

We test the effect of pool membership on patent characteristics in two different ways. First, we test the effect on all the individual characteristics independently. This approach is justified if the variables are used to indicate the same characteristic, for instance the technological significance of the underlying invention. But we also want to investigate the effect of pool membership on specific patent characteristics, such as breadth, generality, significance, and the scope of the essentiality claim. In order to compare these specific patent characteristics between patents introduced by different companies, we also run all our regressions controlling for the number of claims.

We measure the effect at the patent level, but our main explanatory variables vary among firm-pool-period observations (a firm has the same situation with respect to the pool regarding all the patents it introduces at the same time). We therefore cluster standard errors at the firm-pool-period level. For each left hand side variable, we chose the best estimator (negative binomial for all variables except the number of standard sections) using likelihood ratio tests and report the results for the best estimator[48] in Table 5. We run the following baseline regression:

$$Indicator_p = \alpha_0 + \alpha_1 Outsider + \alpha_2 Founding\_patent + \alpha_3 Age\_input_p + \alpha_4 Age\_patent_p + \varepsilon_{py} \text{[1]}$$

with:

$Indicator_p$ = Tested patent characteristics: the number of claims, generality index, number of forward cites and number of standard sections to which the patent is essential

$Outsider$ = Dummy that equals 1 for a patent held by an entrant company (not already member of the pool)

$Founding\_patent$ = Dummy that equals 1 for a patent introduced at the creation of the pool

Age_input_p = Linear age effect of the input (Input date - date of pool creation)

Age_patent_p = Set of dummies for patent age

ε_{py} = Error term i.i.d. among firm-pool-period clusters

We chose to control for the age of the patent[49], age of the input and potential fixed effects for the pools. We also run alternative regressions controlling for the technological classes of the patents. The results, presented Appendix 4, are similar to those presented in the body of this paper. However, as controlling for technological classes potentially capture at least partly the effect that we would like to underline (an evolution of the filing behaviours of the participants[50]), we chose to present in this paper the results without controlling for the technological classes.

4.3 Results

Table 5 presents the marginal effects of our regressions[51]. Column 1 reports the results for our baseline model on the number of claims. In column 2 and 3, we present the same results on the generality index of the patent. Column 4 and 5 presents the results on the number of forward cites. Column 6 and 7 introduce the findings on the number of standard sections for which the patent is essential to.

[48] We also test that our findings are robust to other specifications (OLS). The results are similar to the results presented in the body of this paper and are presented in Table 10 (appendix 5).
[49] Using alternatively linear and non-linear (dummies) age effects. The results are presented with a non-linear age effect.
[50] On this effect, see Nagaoka et al. (2009)
[51] The coefficients are presented in Table 9, a robustness check with OLS is presented in Table 10 (appendix 5).

We successively, for each indicator, (except the number of claims) run the regressions with and without controlling for the number of claims of the patent. Indeed, one of the main potential effects that we discuss in this paper is that patent holders may have incentives to divide their patent filings in order to increase their royalty share. Thus, it is necessary to present our results on the different indicators controlling for the breath of the patent. As the number of forward citations is sensitive to patent age[52], we also present in Appendix 6 the regression results with a full set of application year dummies, technological class dummies and a linear age effect. The results are similar to those presented in Table 5 below.

	(1) NBREG	(2) NBREG	(3) NBREG	(4) NBREG	(5) NBREG	(6) Poisson	(7) Poisson
	DV=Number of claims	**DV=Generality index**		**DV=Number of citations**		**DV=Number of standard sections**	
Outsiders*	6.697*** (2.595)	0.032 (0.023)	0.031 (0.022)	1.853*** (0.554)	1.657*** (0.575)	-0.248** (0.120)	-0.251** (0.118)
Founding Patent*	1.944 (2.118)	0.091*** (0.034)	0.090*** (0.033)	0.345 (0.331)	0.246 (0.339)	0.013 (0.171)	0.008 (0.172)
Age input	-0.041 (0.036)	0.0006* (0.0003)	0.0006* (0.0004)	-0.006 (0.006)	-0.006 (0.006)	0.0006 (0.002)	0.0007 (0.002)
Number of claims			0.0006* (0.0003)		0.018*** (0.006		0.002 (0.002)
Patent age effect	Y	Y	Y	Y	Y	Y	Y
Pool dummies	Y	Y	Y	Y	Y	Y	Y
Observations	1208	707	707	1229	1208	1164	1143
Nb. of clusters	190	141	141	190	190	162	162

*Legend: * p<0.10; ** p<0.05; *** p<0.01. Robust standard error clustered in parentheses.*
(*) dy/dx is for discrete change of dummy variable from 0 to 1

Table 5. Regression Results, Marginal effects

As we can see, there are significant differences in the characteristics of patents introduced by insiders and by outsiders. On this opposition, with a positive and significant marginal effect of 6.69, we can affirm that patents introduced by outsiders are significantly wider than patents introduced by insiders. The effect seems to be huge and robust[53].

[52] For a discussion of patent citations as indicators, see Hall et al. (2001); for a discussion of how to control for patent age and application year effects in patent citation analysis, see Mehta et al. (2009)

[53] Depending on the model tested (Poisson, OLS and NBreg, the marginal effects for the variable *outsiders* vary from 4.45 to 6.69 and are all significant at 5% or 10%. The most conservative approach is a Poisson estimation with dummy variables to control for the technological classes of the patents. In this case, the marginal effect

It means that insiders introduce patents that are almost 7 times narrower than patents included by outsiders. At the same time, these patents are more cited than patents introduced by insiders and this difference is also statistically significant at 1%. There is however no significant difference in generality scores: incumbent members introduce patents that are not significantly more general than the patents introduced by incumbent members.

Furthermore, we can see in Table 5 that patents introduced by incumbent members are essential to significantly more standard sections than patents introduced by outsiders. Between two patents[54] introduced by an outsider and an incumbent member, the number of standard sections to which the patent is essential is 25% lower for the patent held by an outsider.

On the difference between founding and non founding patents, we can underline a positive and significant difference in the generality index. The generality index is 9% higher for the founding patent and this difference is statistically significant at 1%. Thus, patents entered at the creation of the pool are more general than patents introduced later on. This result is quite intuitive, as we expect that the more fundamental and general patents are the first to be introduced. Nevertheless, the difference in the generality index is the only dissimilarity in terms of intrinsic characteristics between founding and non founding patents.

To summarize, we can say that patents entered at the time of the pools' creation are significantly more general than patents introduced later on. This difference is the only one in terms of characteristics between founding and non founding patents. Patents introduced by outsiders are wider than patents introduced by insiders. At the same time, patents held by outsiders are also significantly more cited and less focused on the standard (number of standard sections to which the patent is essential) than patents introduced by incumbent members. These results remain robust if we control for the different breadths of the patent held by insiders and outsiders (using the number of claims). The number of forward citations per claim is significantly higher for patents held by outsiders and the number of standard sections per claim is significantly lower for patents introduced by incumbent members.

As shown in Appendix 7, our results are robust for three pools out of four on which we can effectively estimate the different effects (DVD 6C, AVC and MPEG 4 Visual). For the MPEG 4 Visual pool, we highlight the same difference between patents introduced by incumbents

equals 4.45 and is statistically significant at 10%. We also control for the values taken by our variable *number_claims* using the logarithm of the variable instead. The most conservative marginal effect is in this case 0.428 and is statistically significant at 5%. Nevertheless, the ME can not be interpreted, reason why we chose to present the ME on the *number_claims* variable in Table 5. However, all these findings confirm that there is a significant huge positive impact of the variable *outsiders* on the number of claims of the patent.

[54] with average values on the other explanatory variables

and new entrants in terms of the number of claims, the generality index and the number of citations, but there is no significant difference in the number of standard sections. On the other hand, the MPEG 4 Visual pool is the only pool for which the patents introduced by entrant companies are significantly more general than patents introduced by insiders. There is only one pool out of four (MPEG 2 pool) for which there are no significant differences between the patents introduced by incumbent members and outsiders.

4.4 Discussion

We have shown in this article that patent pools grow over time, as they attract a considerable number of patents after pool launch. The patents introduced after launch are on average filed four years after the founding patents, and they are more incremental. We distinguish between patents introduced by incumbent members and patents introduced by new entrants. We find that a large majority of the patents introduced late are introduced by incumbent members.

When comparing patents introduced at the same time by incumbent members and late entrants, we find that these patents have a similar age and generality score. The first patents introduced by companies joining late are thus younger and more incremental than the founding patents, i.e. the patents which the founding members have first introduced into the pool. This finding indicates that late entries into patent pools are not predominantly an indicator of slow coalition building among a group of companies holding comparable patents. It rather seems that the founding members are those companies that obtained the first essential patents for a standard, while the late entrants obtained their first patents on a later, more incremental stage of the development of the standard.

The pool founding members also account for the majority of the more incremental patents introduced into the pool after its launch. When comparing patents introduced at the same time in the same pool, we find patents introduced by late joiners to be wider and more significant, but less focused on the standard. As a result, the share of the founding members in the pools is very large, and the average significance and width of their patents is below the average significance and width of the patents of late entrants. In spite of the high generality score on founding patents, patents of late entrants are even more fundamental than patents held by founding members. Because of the royalty sharing rules of the patent pools, the respective revenue of the different companies is directly linked to their share in the number of patents. Patent pool founding members can thus capture a great part of the value of the pool with many relatively narrow, incremental and insignificant patents, whereas new entrants capture only very small shares with few relatively wide and significant patents.

We can then discuss various explanations for the correlation between pool membership and the characteristics of patents filed and presented to the pool. One possible explanation is that incumbent members and pool outsiders have a different capacity to inflate their share in the pool through opportunistic patent introduction (see Nagaoka et al., 2009): as pool members partly control the process through which patents are accepted for patent pools, they arguably face a lower entry barrier for introducing their patents. Due to this advantage, they can profitably file narrower and less significant patents than outsiders facing a higher barrier for including their patents into the pool.

Another explanation is that founding members file patents that are more relevant to the standard. This interpretation is corroborated by the higher number of standard sections covered by their patents. There are various possible reasons for this difference. For instance, we have shown that founding members are those firms holding the earliest and most fundamental patents that are essential for a particular standard. This central position could allow them to eventually obtain more easily further essential patents, because they hold technology which is at the very core of the standard. Another potential reason is that pool membership induces a learning effect of the criteria of essentiality practised by the pool, which could make it easier for companies to match their patent files with standard specifications (see Berger et al., 2012). Yet another reason could be that inclusion of a patent into a pool streamlines incremental R&D towards the technology underlying this patent. Delcamp (2012) shows that patents are cited more often after inclusion into a patent pool. The further technological development of a standard is thus more likely to build upon patents included into a patent pool, which implies that the standard will rely relatively more upon the technological assets controlled by the holder of these patents.

Our results allow revisiting several findings of the economic literature on patent pools. Layne-Farrar and Lerner (2011) analyze the determinants of the decision to join patent pools. We show that beyond this coalition building process among holders of existing essential patents, pools grow through a continuous process through which new, increasingly incremental patents with blocking power over the standard are added into existing pools. In this process, incumbent pool members are in a relatively stronger position to defend their share of the standard, while new entrants have to come up with more significant inventions in order to reap equivalent royalty shares. In opposition with the findings of Nagaoka et al. (2009), we thus find that founding members of a pool find it easier than late entrants to inflate their patent share in a pool. Our finding thus provides empirical support for the assumption of

Dequiedt and Versaevel (2012), who argue that companies would rather be founding members of a pool than having to negotiate their entry into an existing pool. From this assumption, Dequiedt and Versaevel derive important implications for the innovation incentives induced by prospective pool creation.

5. Conclusion

In this article, we describe how patents are introduced into patent pools over time. All the pools in our sample grew after their creation by including further patents, and most of them included further member companies. Most additional patents were however introduced by incumbent members. Patents introduced late are increasingly narrow, incremental and insignificant. Especially incumbent members introduce patents that are narrower and less significant than patents introduced at the same time by entrant companies. As a result, the founding members of a pool hold a broad majority of the patents currently included in the pools in our sample, but their patents are narrower, more incremental and less significant on average than the patents held by companies that joined the pool at some time after pool creation. We introduce a novel indicator for the match of patent with the standard underlying the patent pool, and show that insiders introduce patents that are essential to broader parts of the standard. With this indicator, we also make a significant methodological contribution to an emerging literature on firm strategies aiming at matching patent claims with ICT standards.

Due to the royalty sharing rules, the income of the members is linked to their shares of patents included in the pool. The high number of relatively insignificant and narrow patents introduced by founding members could in this context indicate that these companies find it easier to obtain inclusion of their patents. This advantage for the first companies joining a pool could be explained by the fact that these companies have a better bargaining position with respect to the pool, or by the fact that they file patents which are more focused on the underlying standard.

Our findings have important policy implications. On the one hand, a first mover advantage for pool founding members is a powerful tool to overcome free riding in coalition building for creating a pool. On the other hand, the possibility to increase the share in royalty revenue through adding relatively incremental, narrow and insignificant patents after joining a pool might trigger wasteful excess patenting. We thus recommend that patent pool design should take the incentives for opportunistic patenting into account. A particular importance should be attributed to royalty sharing rules and to the criteria for acceptation of patents. Variance in the institutional settings inside our sample is however not informative about how efficient the different rules are. Future research should investigate differences between pools in order to assess the different potential solutions for the problems highlighted in this paper.

Chapter III : Patent Pools and Patenting for Technological Standards

An empirical analysis of the ex-ante effects of contemporary patent pools

Pools de brevets et dépôt de brevets autour des standards technologiques – une analyse empirique des effets ex ante de pools contemporains

Il y a un nombre croissant de pools de brevets mis en place pour les brevets qui sont essentiels à des standards technologiques. L'effet de ces pools sur les incitations à déposer et déclarer des brevets essentiels est pourtant peu étudié. Nous analysons comment le nombre de brevets déposés et déclarés essentiels est affecté par le nombre croissant de pools depuis 1999. En nous appuyant sur un large échantillon de standards NTIC développés entre 1992 et 2009, nous comparons les standards liés à au moins un pool de brevets et les autres standards. Nous montrons que les périodes autour de la création de pools sont caractérisées par un niveau exceptionnellement élevé de dépôts et de déclarations de brevets. Ensuite, nous distinguons les standards développés avant 1999, quand les pools de brevets étaient pratiquement interdits par le droit de la concurrence, et depuis 1999, quand les autorités de la concurrence ont adopté une approche plus permissive. Dans le cas des standards développés plus tôt, les dépôts de brevets culminent suite à la création d'un pool, reflétant une réaction face à un changement exogène inattendu. Dans le cas des standards plus récents, les dépôts de brevets culminent avant la création de pools, et ont lieu généralement plus tôt que pour des standards comparables qui ne sont pas liés à des pools. Ces résultats sont conformes aux prédictions de l'analyse théorique sur les effets d'une création de pool attendue sur les incitations à déposer des brevets. Alors que nos résultats mettent en évidence un effet positif des pools de brevets sur le nombre de brevets déposés et déclarés, le rôle des pools dans le nombre croissant de brevets déclarés essentiels semble toutefois être limité.

1. Introduction

Over the last ten years, the increasing number of patents declared essential to technological standards has attracted wide attention in the academic literature and among policy makers. A patent is called essential for a standard when it is necessarily infringed by any implementation of the standard. Obtaining such a blocking power over a standard may increase the commercial value of a patent for its holder (Rysman and Simcoe, 2009, Bekkers et al., 2002). Standardization thus generates additional incentives for firms to file more patents (Layne-Farrar, 2008, Bekkers et al., 2012), or to adjust their patent files to ongoing standardization (Berger et al., 2012). The increasing number of patents around standardization thereby evolves to become a challenge for standard development and implementation (Shapiro, 2001).

In order to deal with these challenges, standardizing firms have come up with mechanisms to coordinate their strategies with respect to Intellectual Property Rights (IPR). Patent pools are the most important of these mechanisms (Shapiro, 2001). Pools combine IPR of different firms to be licensed out under a single contract. This increases transparency, reduces coordination costs and avoids costly infringement litigation. Pools including only patents which are complementary and necessary for implementing a standard furthermore reduce overall royalty rates by eliminating wasteful multiple marginalization (Lerner & Tirole, 2004). Based upon these arguments, patent pools are generally believed to increase *ex post* economic efficiency, and recent antitrust guidelines have adopted a permissive policy stance towards patent pools including only complementary patents.

The effect of patent pools on the incentives to innovate is however subject to debate. Simcoe (2007) argues that the spreading practice to create patent pools for technological standards is one of the driving factors of the increasing number of essential patents. This claim is supported both by the theoretical literature, predicting a positive effect of pools on innovation incentives, as well as by practitioner reports (Peters, 2011) and case studies evidencing the importance of opportunistic patenting in view of patent pools (Nagaoka et al., 2009, see also Chapter 2). Recent empirical research (Lampe and Moser, 2012; Joshi and Nerkar, 2011-1) nevertheless suggests that patent pool creation was followed by a decline in related patenting. These findings however only describe a decline in follow-on innovation once a number of existing patents were bundled into a pool (the *ex post* innovation effects). The effect of patent pools on the incentives to file patents to be included into this pool (the *ex ante* innovation effects) have so far not been subject to a thorough empirical analysis.

In this paper, we investigate *ex ante* effects of patent pools on patenting and evaluate whether pools increase incentives to file standard-essential patents. Using data on 60,000 declarations of essential patents to more than 700 ICT standards, we first describe the growth in the number of patent declarations over the past twenty years, and discuss to what extent the increasing number of patent pools is likely to have contributed to this evolution.

We then analyze on the standard and firm level whether the creation of the individual patent pools can be related to unusual peaks in the levels of patent declaration and patent files. We build up a comprehensive database of 7 million patents that are technologically close to declared essential patents, filed by over 150 companies contributing proprietary technology to the specific standard. We relate patenting and patent declarations to 700 standards and technical specification and 28 patent pools. We describe the baseline timing of patenting and declaration with respect to the development of technology standards. We then analyze whether there is an unusual change in the extent of patenting before or after the launch of patent pools.

We distinguish between expected and unexpected patent pools, using the favorable business review of patent pools from 1997 to 1999 as an exogenous policy change. While there have been many patent pools in very different technological areas until World War II (Lampe and Moser, 2012), stricter enforcement of competition law impeded any pool creation from the end of World War II until the 1990s (Gilbert, 2004). In 1997 and 1999, the European and American antitrust authorities however authorized a new model of patent pooling for two important standards[55], including several important safeguards against anti-competitive abuses. After this precedent, many other important pools including the same safeguards have been created and authorized. This policy change significantly altered the expectations of standardizing firms regarding the likelihood of successful patent pool creation.

We thus compare two groups of standards related to patent pools: on the one hand, standards released before 1999 were developed in a policy environment hostile to patent pools. The possibility to create a patent pool for these standards only appeared after standard release, once the technological basis for the standard was settled, and companies could only adapt their later patenting decisions to the new situation. On the other hand, firms investing in the development of standards released after this policy change were able to integrate the new policy environment in their investment decisions before the technology for the standard was settled. We will analyze how the timing of patenting around pools differs for

[55] MPEG2 and DVD, see the business review letters:
http://www.justice.gov/atr/public/busreview/2485.pdf,
http://www.justice.gov/atr/public/busreview/215742.pdf.

standards released before and after the policy change. Furthermore, we describe how the timing of patenting differs from standards related to a (foreseeable) patent pool with respect to other standards which are otherwise comparable, but not related to patent pools.

We find evidence for a positive effect of patent pools on patenting and the number of patent declarations. The effect of patent pools depends upon whether the pool creation was expected or came as a surprise to innovating firms. For instance, the periods before pool creation are characterized by high numbers of patent files in the subsample of standards released later than 1999. There is no such relationship in the sample of standards released earlier then 2000. For these standards, the creation of a patent pool is however followed by an immediate increase in the number of patent files. Furthermore, we find that companies entering such a pool increase their level of patenting with respect to companies contributing to the same standard, but staying outside the pool. The overall effect of patent pools on the number of essential patents seems however to be limited. The recent surge in the number of essential patents was mainly driven by standards for which pools were not an option.

2. **Review of the Literature**

The theoretical literature on patent pools generally predicts a positive effect on the incentives to invest in related R&D. Llanes and Trento (2010) finds that patent pools reduce the royalty stacking problem, thus reducing the negative effect of patent protection on follow-up innovation. The majority of the theoretical work however considers the effects of prospective patent pools on ex ante incentives to invest in patents that could be included into the pool. Lerner and Tirole (2004) argue that prospective pools increase the expected return on patents, and thus increase patenting incentives. Lerner and Tirole (2004) find that in the case of pools restricted to complements, this increase is necessarily efficient. Aoki and Schiff (2007) nevertheless find that in some situations prospective patent pools can induce wasteful overinvestment. Dequiedt and Versaevel (2012) analyze the dynamic incentives for R&D in view of a patent pool. In their model, patent pools increase innovation incentives, and especially induce patent races preceding the launch of the pool. Choi (2012) analyzes the effect of prospective patent pools on patenting when the patentability of inventions is subject to uncertainty. He finds that patent pools can be detrimental for innovation because they induce an increase in the number of weak patents.

In contrast to theoretical research, recent empirical advances rather point to a negative effect of patent pools on innovation and patenting. In a study of the sewing machine patent pool in the 19th century, Lampe and Moser (2010) find that this pool had a positive effect on the number of subsequent patent files by insiders and outsiders. Nevertheless, the authors show that the effect on innovation is negative, as measured by indicators of real technical progress. There is thus apparently evidence of an increased patent propensity which does not translate into an increased innovation effort. In a more recent study of patent pools in the 1930s, Lampe and Moser (2012) find that most of these pools had a negative effect on subsequent patenting in the field. In the only existing study of the effects of contemporary ICT patent pools, Joshi and Nerkar (2011-1) find that the creation of the DVD patent pools was followed by a decline in patenting in related technical fields by pool licensors and licensees. All these papers however measure the effects of pooling existing patents on ex post incentives to file subsequent patents.

The existing empirical literature does not address the question whether the known possibility to create patent pools makes it more attractive to develop patentable technologies for new standards. Simcoe (2007) argues that the recent possibility to create patent pools without facing antitrust concerns has contributed to the surge in the number of declarations of essential patents. There is so far however no empirical evidence that would allow to confirm this hypothesis. This paper fills this gap and analyzes the effect of patent pools on the incentives to file and declare essential patents.

3. **Descriptive analysis**

3.1 Patent declarations and standards

The aim of our analysis is to assess whether patent pools have contributed to the increasing number of essential patents for technological standards. In a first step, we identify the totality of declarations[56] of essential patents made from 1992 to 2010 to the main formal standard setting organizations (SSO) which operate on an international level: ISO, IEC, JTC1 – a joint committee of ISO and IEC – CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE[57]. We identify 64,000 declarations of essential patents made by 150 companies. Our measure is based upon a count of declarations, and not a count of essential patents. The number of

[56] A patent declaration is a public statement by a patent holder declaring that his patent is essential to a specific standard. These declarations are made publicly available on the website of the SSO.
[57] These SSOs account for a large part of the essential patents identified by Bekkers et al. (2011). The sample is however restricted to formal SSOs operating with comparable rules on Intellectual Property Rights, thus excluding important SSOs and consortia, such as the IETF.

declarations is higher than the number of patents, because we also include so-called blanket declarations (a generic declaration that a company owns essential patents without specifying the patent number), and we count patents declared essential to various standards as multiple declarations.

These declarations are related to more than 700 standards and technical specifications. The PERINORM[58] database provides detailed bibliographic information on formal standards such as standard version updates, standard amendments, the number of pages, the technical classification and the year of release. In a next step we identify 28 patent pools (including failed attempts to create a patent pool) and match these pools to the standards in our sample[59]. Matching pools with standards is straightforward, as pool administrators clearly display the technological standards that are covered by the patent pool license. For each pool, we inform the date of launch, defined as the date at which a patent pool administrator publishes a call for patents to gather holders of patents that are essential to a technological standard (compare Chapter 2).

3.2 Patent pools and declarations of essential patents 1992 to 2010

We will first use our comprehensive database to describe the historical evolution of patent pools and the rate of patent declarations over the past 18 years. The most immediate effect of the policy change with respect to patent pools can be seen from figure 1: the rate at which new successful pool projects are created is steadily increasing. The increasing experience of companies with pools, the emergence of companies specializing in the administration of patent pools, initiatives by SSOs and standards consortia encouraging pool creation as well as the further clarification of the legal environment contributed to an increasing ease of pool creation. New pools are created both for standards developed prior to the policy change (this is the case for instance for MPEG Audio, MPEG2 and G.729) as well as for new standards.

Furthermore, we can compare the number of companies having joined the patent pool during the first four years after launch. We can see an increasing number of pools attracting a relatively large number of members. Nowadays, companies deciding upon the level of R&D investment for a future standard can integrate a non-negligible probability of successful pool creation into their calculations of the expected return on essential patents.

[58] PERINORM is the world's biggest database with bibliographic information on formal standards and is regularly updated by the SDOs DIN, BSI and AFNOR.
[59] The list of pools, the date of pool launch and the match of relevant standards is provided in Appendix 1.

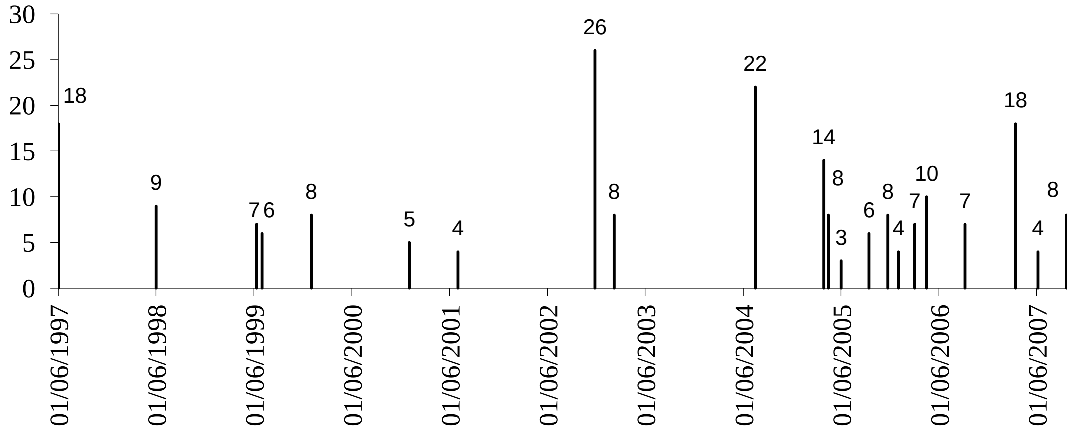

Figure 1 Pool creation and number of members after 4 years

In the following, we can use our declaration database, matched to individual standards, in order to analyze whether the increasingly widespread practice of pooling patents has affected the number of essential patents on new standards. First, our own data confirms a remarkable increase in the number of patent declarations beginning at the end of the 1990s (figure 2). These figures are however to a very large extent driven by declarations made to ETSI, and in particular related to 3G mobile communication standards (indeed, UMTS alone accounts for 11,000 declarations, 3GPP receives 15,000 declarations and AMR-WB 1,500 declarations). It can only be speculated to what extent the various attempts to create a large patent pool on 3G technology have fuelled this unprecedented level of patent declaration. It seems that the role of the (eventually failed) attempts to create important 3G patent pools have not been decisive for the huge number of essential patents on 3G standards[60]. Several of the most important holders of 3G patents have never aimed at joining a patent pool. Furthermore, patenting in this industry seems to be strongly driven by portfolio races between litigious rivals and by the presence of innovation specialists patenting aggressively, notably Qualcomm and InterDigital.

[60] As to practitioners and experts in the telecommunication industry only 8-9% of the GSM standard essential patents are pooled. Attempts by Sisvel and Via Licensing to form pools for LTE have yet not been successful even though there have been meetings to pool LTE patents since more than 2 years.

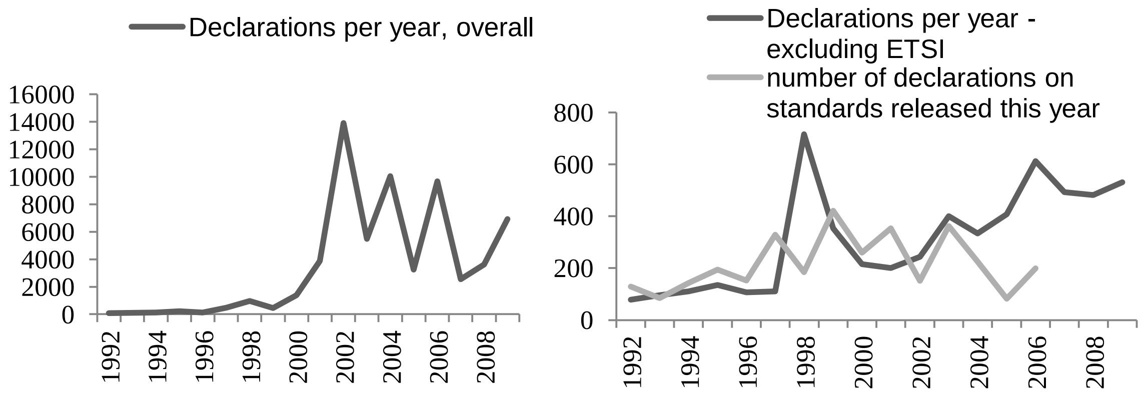

Figure 2 Declarations per year (whole sample left graph) Declarations per year and per year of release (excluding ETSI right graph)

Setting aside ETSI and the 3G mobile phone standards, we focus the analysis on ISO, IEC, ISO/IEC (JTC1), CENELEC, ITU and IEEE. These are standard bodies that, even though they account only for limited numbers of essential patents (compared to ETSI and IETF), are related to 24 out of the 48 pools in our database, including many of the most important ones.

Concentrating on these standards, we can still see an increase in the number of declarations at the end of the 1990s (dark grey line in the right graph of Figure 2). The graph also exhibits a spike in the number of patent declarations in 1998. Possibly, this spike includes several declarations of essential patents made as an immediate reaction to the contemporaneous policy change. In order to analyze whether there was a lasting change in the levels of patenting related to new standards after this year, it is important to relate the number of declarations to the year of standard release. By comparing how many patent declarations standards receive in the first four years after release, we can see that standards issued after 1997 indeed include a higher number of essential patents, even though there is no obvious trend, and the numbers are in decline since 2003 (light grey line in the right graph of Figure 2).

We can go further in the analysis of these trends by comparing different types of standards in our sample. For instance, patent pools are a solution tailored to single large standards including many patents held by many different owners. In the following figure 3, we can however see that the increasing number of patent declarations on new standards is mainly driven by an increasing number of standards including patents.

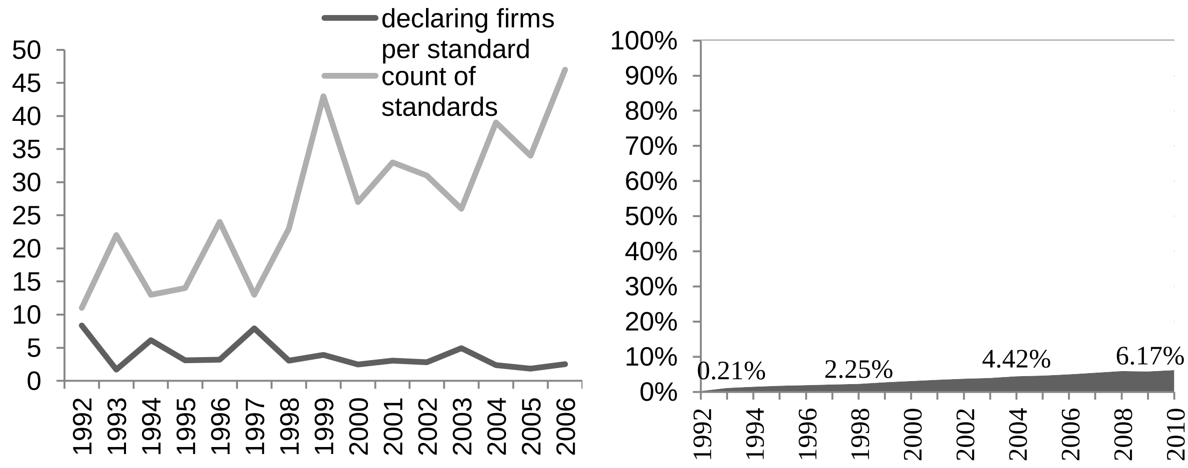

Figure 3 Number of declaring firms per standard and standards including essential patents released per year (excluding ETSI), and the percentage of ICT standards including essential IPR (right graph)

The right graph reveals that an increasing share of the standards released by the SSOs in our sample receive at least one declaration of essential patents. At the same time, the average number of declaring firms per standard has decreased over this period.

This finding could indicate that the increasing number of patent declarations is driven by many small standards, for which pools are not really an option. We thus concentrate our analysis on standards including declarations by more than 4 firms. Analyzing this restricted sample, we find important numbers of patent declarations on standards released from 1997 to 2003, but no steady increase neither in the overall number of declarations on such standards, nor in the average number of declarations by standard (figure 4).

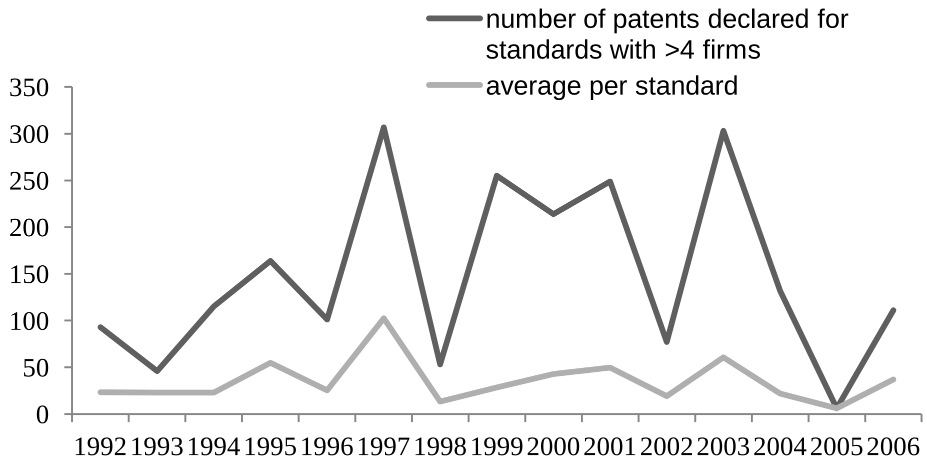

Figure 4 Number of patent declarations to standards receiving declarations from more than 4 firms, and average number of declarations for each of these standards (excluding ETSI)

The analysis of the trends in the number of patent declarations over the past twenty years indicates that the increasing number of patent declarations is on the one hand accountable to 3G mobile communication standards and on the other hand to a high number of standards including few essential patents. While this analysis suggests that patent pools have not been a main driver of the recent increase in the number of essential patents on standards, the analysis of the time trends does not allow concluding on the effect of patent pools on the incentives to file and declare essential patents. Indeed, the aggregate figures are affected not only by the policy change with respect to patent pools, but also by a strong variability in the rate of technological progress, by other policy changes with respect to disclosure obligations and reasonable royalty rates, and by a strong heterogeneity between standards released in different periods. In order to analyze the effect of patent pools on declarations and patenting, we will therefore proceed to an analysis on standard level, analyzing how patent pools affect the level and timing of patenting and declarations for each company and standard.

4. Patent pools and the dynamics of patenting

4.1 Methodological Approach

We will next analyze how the rate of patenting and declaring patents relevant for specific standards is affected by patent pools. The patents that are declared essential only constitute a share of the patents filed in view of technological standards. Indeed, very often rivaling firms develop competing technological solutions for the same problem of a standard. If only one of the proposed solutions is chosen for inclusion into the standard, the patents protecting the competing technologies are not essential patents, even though they have been filed as part of the technological development of the standard. In order to identify standard related patent files, we use the 7-digit IPC classification of the declared essential patents, and count the number of patents filed per year in the respective IPC classes. We use all ICT patents filed at the three major patent offices (USPTO, JPO and EPO) from 1992 to 2009 by the firms declaring at least one essential patent for the respective standard, using the PatStat database and the merging methods of Thoma et al. (2010). This merging yields 7 million patents filed by over 150 firms. To create our explained variable, we computed for each company-standard pair and year the number of priority patents filed in the relevant IPC classes for the standard of observation.[61]

We thus have two measures of standard-related patents: declared essential patents, and related patents filed by the same companies. We relate the timing of patenting and declarations to the timing of pool creation. We define the pool creation as the initial call for patents, often made upon the initiative of a group of patent holders wishing to create a pool who seek to identify and federate the remaining patent holders. The call for patents thus indicates the time where the prospective pool creation becomes common knowledge. In the period preceding the call for patents, several companies can already negotiate on eventual pool creation, but at this stage there is still uncertainty on whether a patent pool will be launched. In addition to the launch of the pool, we identify the dates at which the companies joined the pools using internet archives and the history of news releases of the pool administrators (cf. Chapter 2).

We further create control variables such as a yearly count of all patent declarations on formal standards[62] and a patent count of all patents per year in the IPC classes “G” and “H”[63]. The latter two variables should account for technology shocks in the technical field and organizational changes in the SSOs. We also control for informal industry alliances arising around standardization. Consortia are matched to formal standards using liaison

---

[61] We further conduct tests of the technological position of standards as well as size measures to prove that our matching method reliably identifies standard-related patents. The method and the various tests have been presented at the Patent Statistics for Decision Makers Conference 2011 at the USPTO.

[62] We labeled each patent declared essential to each standard as one declaration. For example a patent declaration for two patents declared essential to two different standards is counted as four declarations. Empty or so-called blanket patent statements - i.e. statements of ownership of essential IPR that do not provide patent numbers - were also counted as one declaration.

[63] “G” and “H” IPCs are technologies that can be connected to information and communication technologies. In our database of standard essential patents 95% of all patents are classified in in both or at least one of these IPC.

statements[64]. If an official liaison statement was not given, we conducted a more detailed analysis in order to identify the related standard. In total 21 different informal consortia could be related to 63 formal standards including essential patents.

All information is given in longitudinal data over 18 years. This broad database allows testing the impact of patent pools on the number and timing of patenting controlling for fixed effects of company-standard pairs, activities in standardization and exogenous technological shocks.

4.2 The counterfactual

In order to analyze the effects of patent pools, we need to compare the empirically observed patenting and declaration rate with the counterfactual rate that would have been observed for the same standard, the same company and the same year in the absence of a pool. The existing empirical literature on patent pools compares the levels observed after pool creation with the levels before pool creation, or with the hypothetical values which would be observed if these rates had continued to follow a general trend pre-existing to pool creation (Lampe and Moser, 2012), or if the patenting of pool members had evolved in a manner similar to the patenting of other firms (Lampe and Moser, 2012; Joshi and Nerkar, 2011-1).

We opt for a similar approach, especially tailored to the analysis of patent pools related to technological standards. The development of the essential technology for a standard does not follow a steady linear increase or decrease, nor do patent files and patent declarations for different standards increase or decrease at the same time. Rather, we will show that the patenting and declaration rates follow an inverted U-shape over the development of the specific standard: the number of patent files related to technological standards increases up to the year of standard release and eventually declines, while the number of declarations culminates three years later. We will control for this baseline timing of patenting and declaration with respect to standardization by including a full set of standard age dummies. We furthermore control for different levels of investment in different standards with company-standard pair fixed effects.

In order to increase the robustness of our results, we estimate the baseline timing for different samples of standards. We present results based upon the sample of standards related to patent pools, the full sample of standards including at least one essential patent, and a sample of standards which are similar to the standards related to a pool based upon observable characteristics. Patent pools are more likely to be created for standards including

[64] A liaison implies an accreditation and a cooperative standardization development between the formal and informal standards bodies.

many essential patents from many different firms (see Appendix 3). These standards are at the same time likely to involve more important commercial stakes and higher technological complexity. The number of contributing firms, the commercial stakes and the technological complexity of the standard could have an impact upon the timing of patenting. We therefore build up a sample of comparable control standards. To account for technological complexity, we restrict the sample to standards related to R&D consortia (for an extensive discussion, see the following Chapter 4). We furthermore restrict the sample to standards including patents from at least four different firms, out of which at least one non-practicing entity. This restriction makes sure that we include only commercially important standards, for which patent licensing is a profitable source of income. We then carry out a propensity score matching based upon the observable characteristics of the standards (see appendix 4).

4.3 The policy change

As mentioned before, the favorable business review by European and American competition authorities of two large pool licensing schemes between 1997 and 1999 constitute a major policy change. While no patent pool has been authorized between 1945 and 1997, after 1999 many other patent pools followed the examples of MPEG2 and DVD. Including very similar safeguards as the pools previously authorized, none of these pool creations has met any resistance from antitrust authorities. *"The DOJ business review letters provide **a template** for patent pooling arrangements that should not run afoul of the antitrust laws. The letters embody a new thinking in economics and law and **contrast sharply** with early judicial opinions about the legality of patent pooling arrangements."* (Gilbert, 2004).

In the following, we will use this policy change to identify the effects of expected pool creation on patenting incentives. It is reasonable to assume that companies developing technology for a new standard after the issuance of the business review letters had different expectations of the likelihood of pool creation than companies working on a standard before this policy change. We will analyze how these expectations in turn affect their patenting behavior. We therefore compare three samples of standards: standards that have never been related to a patent pool, standards developed before the policy change, but eventually related to a pool created after 1999, and standards developed after the policy and related to a patent pool. Using the policy change as exogenous source of variation, we are able to distinguish between the effects of patent pools and the characteristics of standards for which standards are more likely to be created.

4.4 Patent pools and the timing of patent declarations

We wish to analyze how the pooling of patents affects the rates at which companies file and declare essential patents. Therefore we compare the level and timing of patenting and patent declarations between standards related to a patent pool and standards licensed out individually. We furthermore distinguish between standards released before and after the policy change with respect to patent pools.

As discussed, we have constructed two counts of standard-related patents: patent declarations and patent files in standard relevant IPC classes. We first analyze the timing of patenting and declaration with respect to standard development. Figure 5 compares the timing of our two measures around a standard release. In standardization, the release of the first standard version represents an important event. The first standard version specifies the core technological components that determine imminent standardization. Even though standards are regularly updated and may consequently progress in their technological scope beyond release, the first version often specifies a technical trajectory for ongoing development phases.

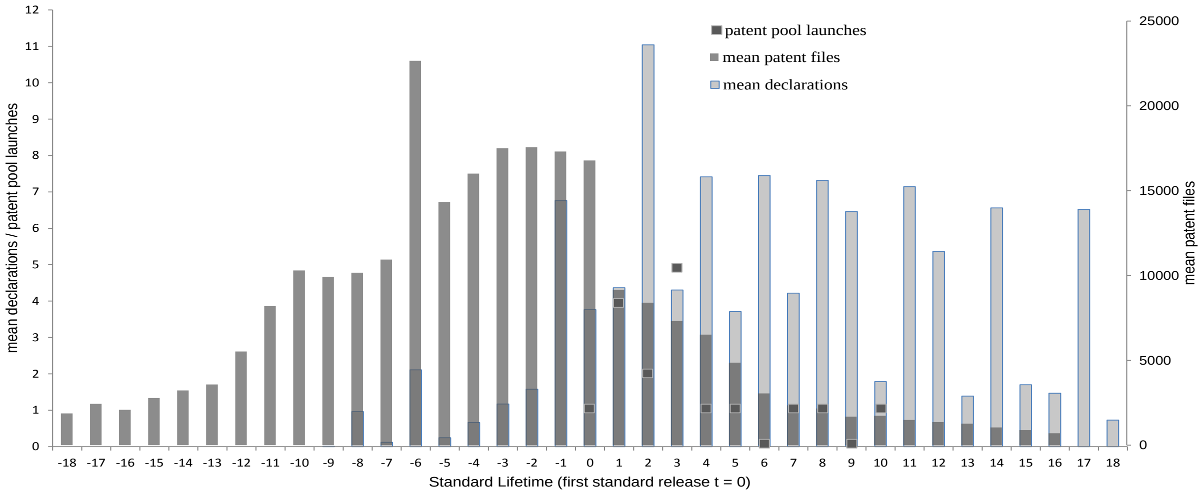

Figure 5 Patent files and Patent Declaration as to pool timing

The figure reveals the typical timing of patenting and patent declarations along the development of a technological standard. Most patents are filed during the four years preceding the first standard release, when the technological basis of the standard is under development. Most declarations are made after the first standard release. Furthermore the count of patent declarations is rather volatile and has a steeper peak around standard release compared to patent files. The graphical analysis shows that the patent count variable also measures some early R&D activities prior to standardization.

We next compare if firms' patent declaration timing differs when patents are pooled or not. In figure 6 we plot the mean patent declaration per firm over standard age. Both graphs show a peak of declaration around the year of standard release. This underlines our argument that the first version contains a major part of the standard's technology components. However, the figure also illustrates that standards related to pools exhibit an unusually high level of declarations in later periods. In comparison, standards without pools experience an almost steady decrease of patent declarations after release.

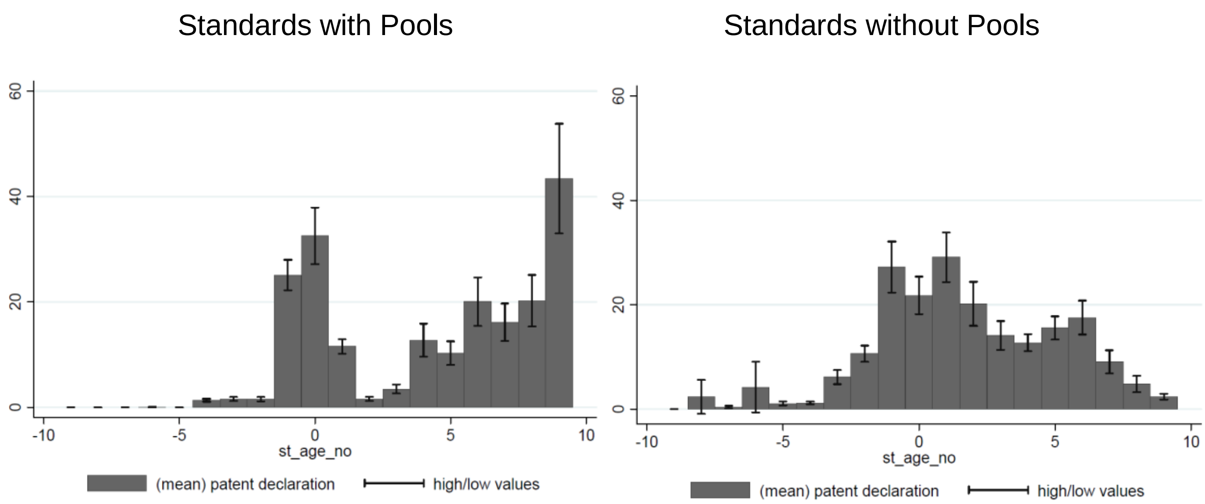

Figure 6 Patent declaration as to standardization timing if patents are pooled or not

In order to analyze whether the unusual peak in declarations well after standardization is related to pool creation, we turn to a panel data analysis. The unit of observation is a one year time span for each standard. We control for standard fixed effects, the baseline timing of declaration along standard development, for exogenous technology shocks and for standardization events (such as modifications or releases of new versions). We can then test whether the creation of a patent pool is related to an otherwise unexplained high level of patent declarations by introducing dummies for two-year periods around pool creation. We thus estimate the following poisson regression:

$$n_{S,Y} = \exp\left(\alpha_i PC_{S,Y+3} + \alpha_{ii} PC_{S,Y+1} + \alpha_{iii} PC_{S,Y-1} + \alpha_{iv} PC_{S,Y-3} + \theta S_S + \delta T_S + \eta S_{S,Y} + \zeta T_{S,Y} + \varepsilon_{S,Y}\right)$$

Where $n_{S,Y}$ is the number of declarations per standard per year, $PC_{S,Y+3}$ to $PC_{S,Y-3}$ are dummy variables for the timing with respect to pool creation, S_S and T_S are time-invariant standard and technology characteristics, $S_{S,Y}$ and $T_{S,Y}$ are time variant standard and technology characteristics, and ε is an idiosyncratic error term. In the fixed effect specification, S_S and T_S are replaced by a standard fixed effect.

The full regression results can be consulted in appendix 2. The following figure 7 plots the estimated coefficients for the periods around pool creation. We can see that these periods exhibit significantly positive coefficients. The estimated coefficients are at the highest for the periods immediately preceding pool creation; and significantly decrease thereafter. This finding could indicate that preparations for pool creation trigger unusually high levels of the declaration rate well after standard release (indeed patent pools are usually launched several years after standard release). Alternatively, it could also indicate that patent pool creation is a reaction to periods of an unusual intensity of patent declarations.

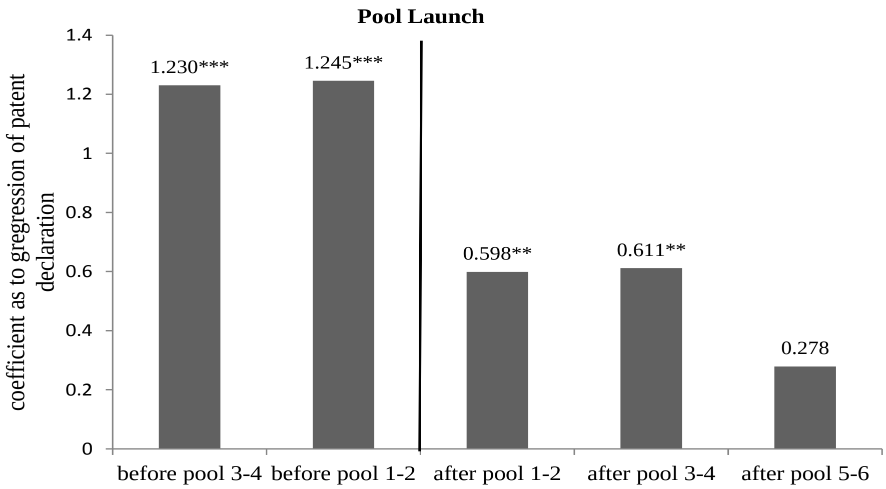

Figure 7 Coefficients on timing with respect to pool launch[65]

4.5 Patent pools and the timing of standard-related patenting

In a next step, we plot the evolution of our count of standard related patent files per firm standard pair over standard age. Again the two graphs in figure 8 illustrate that the timing of patenting differs when patent pools exist. Compared to the bell shaped distribution of patent files around the release of standards without pools, we observe an increase of patenting several years after the first release when the standard is related to a pool. Indeed most patent pools are formed several years after standard release. However, we have to be cautious in interpreting these shifts of patenting or patent declaration. On the one hand, we could argue that patent pool formation increases incentives to invest in R&D, leading to a peak in patent files that deviates from the normal timing of patenting around standard development. On the other hand, we could argue that patent pools are particularly formed for standards that are subject to ongoing technology development beyond standard release.

[65] $***$, $**$,and $*$ imply significance at the 99%, 95%, and 90% levels of confidence, respectively

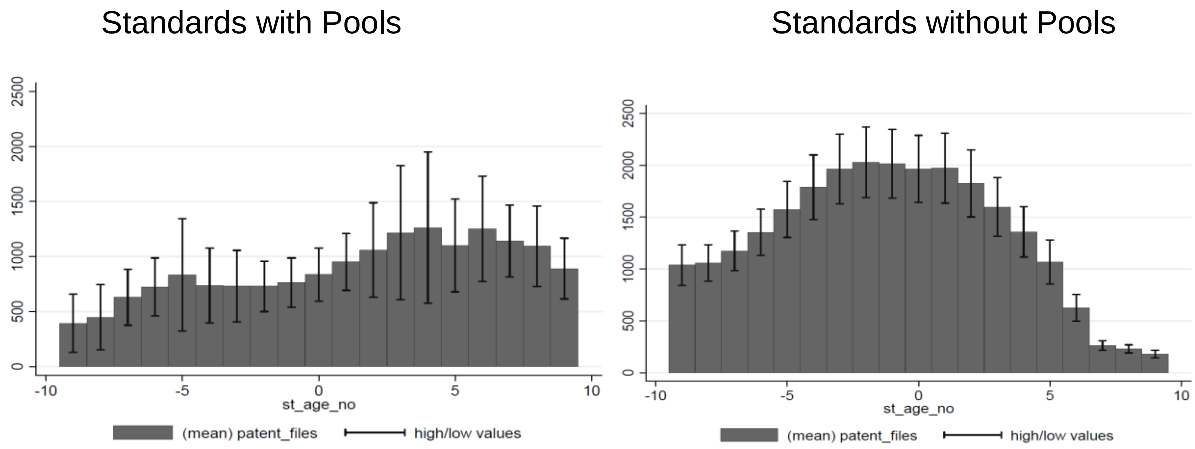

Figure 8 Patent files as to standardization timing if patents are pooled or not

Once again, we analyze whether the unusually high level of late patenting on standards related to patent pools can be connected to the timing of pool creation. We therefore graph patent files per company over time with respect to pool creation. We distinguish between pools for standards released before and after 1999.

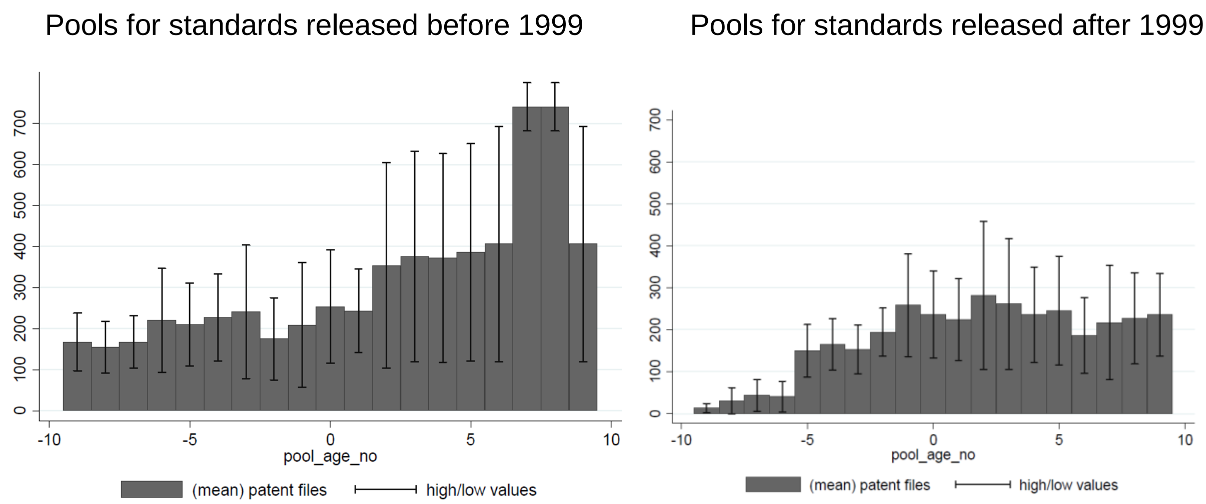

Figure 9 Patent files as to pool timing, standards released before and after 1999

Figure 9 illustrates patent files per firm as to pool timing for standards released before and after 1999. The graph for standards released after 1999 does not show clear evidence for a specific timing of patenting as to the creation of patent pools. We have discussed earlier that the business review of antitrust authorities ensured a legal certainty in periods after 1999. We have argued that for standards released after this date, the possibility of an eventual pool creation can be taken into account by the companies while investing in standard related R&D during the standard development phase. In comparison, for standards released before 1999, there is a strong peak in patent files well after the initial launch of a patent pool. These differences support our approach to distinguish between pools created for standards released before and after policy change. However, difference in the timing of patenting around pool creation between earlier and later standards could also be due to changes in the general dynamics of standardization, rather than the effects of a policy change on the expectations of pool creation. We therefore carry through a further analysis where we include a group of comparable control standards to account for generic changes in standard dynamics.

4.6 Patent pools and time shifts

We apply an additional analysis in order to examine the effects of expected pool creation. As we want to analyze the effect of a prospective pool launch on the overall timing of standard-related patenting, we need a counterfactual group of standards that are closely comparable with the standards related to patent pools. We therefore compare standards related to patent pools with our sample of comparable control standards (see Appendix 4).

We then compare the timing of patenting around standard development between the different groups of standards. We estimate the number of standard-related patent files by firm standard pair and year, controlling for fixed effects, persistent effects of transitory shocks, standard age dummies, and events affecting the standard and exogenous factors in the field. We test for the time-shifting effect of patent pools by including a linear standard age variable, which we interact with the dummy variable indicating that the standard is related to a pool. As in the previous analysis, we estimate this effect separately for standards issued before and after the policy shock[66] (results can be consulted in the appendix 5).

We estimate coefficients on the whole sample from 1992 to 2009. In order to avoid truncation of the observation period, we include for all standards only observations for the four years preceding and the four years following to standard release and restrict the sample to standards issued from 1995 to 2005 (results are robust to estimating the model over the full sample and the full observation period). We find that patent pools for standards released after the policy change are connected with patenting taking place earlier in the standard life-time. We further conduct test of statistical differences for periods before and after the policy

[66] As we are now interested in effects of patent pools on R&D investment made early in the standard life time, we decided to divide the sample at a later date. For instance, we cannot expect that the policy change from 1997 to 1999 led to an earlier start of R&D investment for standards released in 2000. We somehow arbitrarily chose the release date of 2002 as a separating line, but within reasonable bounds the results are not sensitive to the precise date separating the samples.

shock. The results reveal significant differences, ensuring that the time shift of patenting is specific to later standards.

4.7 Anticipation and reaction to pool creation

In order to confirm these descriptive findings, we apply econometric analysis to control for heterogeneity and isolate the pool timing effect. We use our panel of firm standard pairs over the timespan of 1992-2009. Thus we are able to make use of the baseline timing of standardization while testing for specific effects around the time when a pool is launched. All firms are observed over the whole period of time. Following our discussion of the importance of expectations, we distinguish between standards released before and after the policy change. We interact the pool dummies with a variable indicating whether the standard was released before or after 1999. We test the following specification:

$$st\ patents_{ijt} = \exp\big(\alpha_1\ st\ patents_{ijt-1} + \beta_1\ before\ pool\ active_{jt\ PL-3/4} * years\ later\ 1999_{\ j} + \beta_2\ before\ pool\ active_{jt\ PL-1/2} * years\ later\ 1999_{\ j} + \beta_3\ after\ pool\ active_{jt\ PL+1/2} * years\ later\ 1999_{\ j} + \beta_4\ after\ pool\ active_{jt\ PL+3/4} * years\ later\ 1999_{\ j} + \beta_5\ before\ pool\ active_{jt\ PL-3/4} * years\ earlier\ 2000_{\ j} + \beta_6\ before\ pool\ active_{jt\ PL-1/2} * years\ earlier\ 2000_{\ j} + \beta_7\ after\ pool\ active_{jt\ PL+1/2} * years\ earlier\ 2000_{\ j} + \beta_8\ after\ pool\ active_{jt\ PL+3/4} * years\ earlier\ 2000_{\ j} + \beta_9\ CT\ patent\ count_t + \beta_{10}\ standard\ activity_{jt-1} + c_t + \varepsilon\big)$$

Where we count st $\mathrm{patents_{ijt}}$ filed by firm i that are relevant to standard j per year t, $\mathrm{before\ pool\ active_{jt\ PL+3/4}}$ equals one 3 to 4 years before the pool launch PL for standard j in year t, $\mathrm{before\ pool\ active_{jt\ PL-1/2}}$ equals one 1 to 2 years before the pool launch PL for standard j in year t, $\mathrm{after\ pool\ active_{jt\ PL+1/2}}$ equals one 1 to 2 years after the pool launch PL for standard j in year t, $\mathrm{after\ pool\ active_{jt\ PL+3/4}}$ equals one 3 to 4 years after the pool launch PL for standard j in year t, $\mathrm{years\ later\ 1999_{\ j}}$ is a dummy variable that equals one if a standard j is released later than 1999, $\mathrm{years\ earlier\ 2000_{\ j}}$ is a dummy variable that equals one if a standard j is released earlier then 2000, $\mathrm{CT\ patent\ count_t}$ denotes all worldwide ICT patent files for each year t, $\mathrm{standard\ activity_{ijt-1}}$ denotes version releases and amendments to standard j in year t-1, $\mathrm{c_t}$ are year dummies and ε is an idiosyncratic error term.

We restrict our standard firm pair panel to standards for which a pool has been created at some time, and further control for unobserved heterogeneity using fixed effects. Thus we rely on a sample of standards that is subject to a comparable pattern. Rather than accounting for pre-existing trends or supposing linear evolutions, we include a full set of standard age dummies to control for the bell shaped baseline pattern of patenting around standardization observed in the descriptive analysis. We furthermore control for particular events affecting the standard in question (including variables for standard upgrades) and for technological shocks in the wider technological field (including the overall number of ICT patents files in the categories G and H per year). We furthermore control for persistent effects including the lagged dependent variable as control variable. We use a poisson estimator with robust standard errors, and furthermore cluster standard errors by firms (clustering standard errors by standards instead does not alter the results). In models M1a-M1c we sequentially include our control variables of standard updates and lagged patent files to ensure independency from our main explanatory variables. In M2 we only use observations of member companies and thus reduce our sample from 242 to 93 group observations. In M3 we also include variables accounting for the timing of pool member entrance. This is due to the possibility that firms which are prospective pool members might react on both, the time when the pool is created and the time when they actually join the pool. All models show robust results for our main explanatory variables.

The results corroborate our methodology to distinguish between standards released before and after the policy change with respect to patent pools. Indeed, the link between patent pools and patenting is very different in the two different samples. For standards released earlier than 2000, we can observe that the creation of a patent pool is immediately followed by an unusually high level of patenting. This group of standards has been released at a time when the prospect of pool creation was still very uncertain. Pool creation became common practice after 1999, when these standards were already released. In comparison, we do not evidence any significant reaction to the creation of patent pools in the sample of standards issued later than 1999. However, our results indicate an anticipatory effect. Periods up to 4 years before pool launch have a significant positive effect for observations of pools related to standards released after 1999.

Firms that declare patents to standards where a pool will be created may react to two events: first, the launch of the patent pool and second, the timing of joining the pool as a full member. In the last model we therefore also include the timing of joining a patent pool. In comparison to M1-M3 our last model differentiates the timing of two effects. The effects of the pool creation remain unchanged. In the case of standards released after 1999, firms show no reaction in periods before or after joining a pool. In comparison, firms active in pools for standards released before 1999 show an incremental positive reaction immediately after joining the pool. This effect last for up to 4 years. However, for the latter sample of firm-standard pairs, the positive effect of pool creation is still slightly stronger compared to the effect of actually joining the pool.

DV= patent_files	M1a	M1b	M1c	M2	M3
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
3-4 y. before pool launch (later 1999)	0.122*** (0.027)	0.151*** (0.028)	0.149*** (0.027)	0.162*** (0.028)	0.145*** (0.033)
1-2 y. before pool launch (later 1999)	0.122*** (0.035)	0.136*** (0.029)	0.127*** (0.031)	0.114** (0.045)	0.152*** (0.037)
1-2 y. after pool launch (later 1999)	-0.006 (0.045)	0.043 (0.036)	0.027 (0.04)	0.122* (0.066)	0.050 (0.035)
3-4 y. after pool launch (later 1999)	-0.074* (0.044)	-0.076* (0.04)	-0.071* (0.041)	0.039 (0.064)	-0.056 (0.04)
3-4 y. before pool launch (earlier 2000)	0.071 (0.066)	0.078 (0.062)	0.090 (0.064)	0.024 (0.064)	0.188*** (0.056)
1-2 y. before pool launch (earlier 2000)	0.032 (0.083)	0.075 (0.062)	0.091 (0.063)	0.04 (0.068)	0.129* (0.068)
1-2 y. after pool launch (earlier 2000)	0.350*** (0.128)	0.330*** (0.12)	0.340*** (0.116)	0.468*** (0.109)	0.268*** (0.085)
3-4 y. after pool launch (earlier 2000)	0.159 (0.108)	-0.023 (0.056)	-0.019 (0.056)	0.055 (0.085)	-0.065* (0.037)
patent files in G and H [1]	0.011*** (0.002)	0.010*** (0.002)	0.010*** (0.002)	0.011*** (0.002)	0.010*** (0.002)
Lag1 patent files		0.076*** (0.011)	0.075*** (0.011)	0.071*** (0.012)	0.077*** (0.008)
Lag 1 standard upgrade			-0.022* (0.013)	-0.048*** (0.016)	-0.018 (0.013)
1-4 y. before pool entry (earlier 2000)					0.067 (0.047)
1-4 y. before pool entry (later 1999)					-0.065 (0.06)
1-2 y. after pool entry (earlier 2000)					0.175** (0.071)
3-4 y. after pool entry (earlier 2000)					0.232** (0.113)
1-2 y. after pool entry (later 1999)					-0.102* (0.059)
3-4 y. after pool entry (later 1999)					-0.028 (0.057)
Standard Year Dummies	Included	Included	Included	Included	Included
Observation	3,928	3,928	3,928	1,473	3,928
Groups	247	247	247	93	247
Log likelihood	-476,922	-446,830	-445,701	-190,429	-438,846

Note: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively.
[1]Coefficient multiplied by 1,000 to make effects visible.

Table 1: Patent files around pool creation and entry into a pool

4.8 Robustness

In our first models (M1-M3), we compared the observed rate of patenting with the baseline evolution of patenting over standard age estimated exclusively for standards which are licensed through patent pools. This makes sure that we work with a sample of comparable standards and reduces heterogeneity. Even though patent pools affect different standards at a different time, the estimated baseline timing of patenting with respect to standard development is nevertheless not unaffected by patent pools. In a first robustness check, we thus compare the timing of patenting for standards related to pools with the timing around standards where pools do not exists. We therefore make use of our whole sample of standards where at least one patent has been declared essential, consisting in 1,704 firm standard pairs. We estimate our third model (M1c) over the expanded sample (M4-1).

Standards where patent pools exist however differ significantly from other standards in technological characteristics and in the characteristics of the contributing firms (see Appendix 3). We gradually reduce our sample to better account for these differences. To account for differences in contributing firms, we identify firms which are technological outsiders with respect to other firms also contributing to the same standard. Indeed, firms may have a different patenting timing when they specialize on different technologies relevant for the standard. In order to limit this firm specific heterogeneity, we measure the technological difference between the essential patents declared by different firms using the overlap of IPC classes. In model M4-2, firms are dropped if their technological focus differs strongly from the average focus of other firms[67].

Another source of heterogeneity between firms is that different firms can be differently affected by specific technology or business cycles. Our sample covers 18 years during which markets and technology have changed in a volatile manner, with many technology-intensive firms disappearing during the internet crisis and new actors appearing. In order to obtain a sample of firms with a comparable overall evolution, we identify positive or negative shocks to the number of employees of firms (M4-3). We observe differences in one year periods, indicating mergers, acquisitions, restructuring etc. If this shock takes place after 2000, all observations after the shock are dropped for this firm, if the shock takes place earlier, we drop all previous observations. Firms with more than one shock are dropped altogether.

[67] We drop the 5% of firm-standard pairs with the highest technological distance to the other firms investing in the same standard

DV= patent_files	M4-1	M4-2	M4-3	M4-4	M4-5
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
3-4 y. before pool launch (later 1999)	0.177*** (0.064)	0.177** (0.084)	0.159* (0.096)	0.057 (0.05)	0.166*** (0.045)
1-2 y. before pool launch (later 1999)	0.220*** (0.061)	0.209*** (0.076)	0.197** (0.092)	0.116* (0.065)	0.095** (0.046)
1-2 y. after pool launch (later 1999)	0.071 (0.052)	0.037 (0.061)	0.043 (0.078)	0.069 (0.074)	0.027 (0.041)
3-4 y. after pool launch (later 1999)	-0.186 (0.127)	-0.244** (0.119)	-0.233* (0.123)	-0.006 (0.087)	-0.061 (0.041)
3-4 y. before pool launch (earlier 2000)	-0.115** (0.055)	-0.084 (0.079)	-0.043 (0.067)	0.035 (0.077)	0.199*** (0.069)
1-2 y. before pool launch (earlier 2000)	-0.112* (0.067)	-0.047 (0.089)	-0.009 (0.085)	0.026 (0.1)	0.133 (0.081)
1-2 y. after pool launch (earlier 2000)	0.347* (0.184)	0.428** (0.185)	0.446*** (0.172)	0.452*** (0.148)	0.413*** (0.103)
3-4 y. after pool launch (earlier 2000)	-0.014 (0.055)	0.025 (0.074)	0.103 (0.102)	0.106* (0.063)	0.098 (0.104)
patent files in G and H [1]	0.009*** (0.001)	0.009*** (0.001)	0.008*** (0.001)	0.004*** (0.001)	0.008*** (0.001)
Lag 1 standard upgrade	-0.020 (0.013)	-0.031** (0.015)	-0.028** (0.011)	-0.042*** (0.01)	-0.033** (0.013)
Lag1 patent Files	0.007*** (0.001)	0.006*** (0.001)	0.004*** (0.001)	0.007*** (0.001)	0.005*** (0.001)
Standard Age Dummy earlier 2000	0.001 (0.001)	0.001 (0.002)	0.002* (0.001)	0.005*** (0.002)	0.003* (0.001)
Sample Restrictions	None	Tech outsider	Employee shock	PSM	Pool Exists
Standard Year Dummies	Included	Included	Included	Included	Included
Observation	27,147	19,560	13,197	6,675	2,521
Groups	1,704	1,227	972	482	171
Log likelihood[2]	- 25,596	- 13,682	- 7,310	- 2,185	-288

Note: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. $***$, $**$,and $*$ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] values in thousand.

Table 2: Robustness analysis

Another concern is heterogeneity among standards. We thus exclude firm-standard pairs for standards that were not matched in our sampling analysis (Appendix 4), and estimate model M4-4. In our last model we again restrict our sample to standards where pools exist, retaining the restrictions with respect to technical outsiders and employee shocks. All models show robust results for both the anticipation effect before pool launch for standards released later than 1999, and the prompt reaction in periods after pool launch for standards released before 2000.

4.9 Discussion

We have highlighted unusually high levels of patent declaration and patenting around the time when a patent pool is launched. For instance, we have shown that standards related to a patent pool exhibit a peak in patent declarations well after standard release. The rate of patent declaration is especially high in the two years preceding pool launch. When changing our level of analysis to the firm standard level, we have furthermore shown that there is an unusually high level of standard related patenting in the periods around pool creation. In the case of standards released after the policy change with respect to patent pools, patenting takes place before pool creation, whereas in the case of standards released before the policy change, the unusually high level of patenting takes place in the periods immediately after the creation of a pool. Furthermore, companies increase their level of standard-related patenting after joining the pool. As compared with other standards, early standards related to a patent pool are characterized by a peak in patenting occurring several years after standard release. Later standards related to patent pools do not exhibit unusual peaks of late patenting and overall patenting takes place in earlier periods than for standards not related to a pool or for standards related to a pool, but released before the policy change.

In principle, finding a correlation between pool creation and periods of strong patenting and high rates of patent declaration is not necessarily evidence for a causal effect of patent pools. As patent pools are conceived a solution to the problems of large numbers of complementary patents, it is plausible that periods of unusually strong patenting or high declaration rates lead to launches of patent pools. This argumentation does however not explain why the creation of patent pools for standards released before the policy change is followed by an increase in patenting. In the case of these standards, pool creation can be considered as an unexpected response to an exogenous policy change. While several companies initiated the project to create a pool before 1997, the favorable business review revealed new information on a more permissive policy stance. The direct increase in patenting as a reaction to pool creation, especially but not only by pool members, can therefore be interpreted as an immediate reaction to newly revealed information. The distinction between standards released before and after the policy change is indeed a crucial condition for interpreting our findings as evidence of causal effects of patent pools.

We have argued that the favorable business review of patent pools in 1997 and 1999 created a template for viable pool licensing schemes. Companies investing in R&D related to standards released after this policy change could take the creation of a possible patent pool into account. Due to the benefits of patent pools for holders of essential patents, the prospective creation of a patent pool is expected to induce companies to increase their efforts to obtain essential patents (Lerner and Tirole, 2004, Aoki and Schiff, 2008). Dequiedt and Versaevel (2012) expect that this induced effect takes place before the pool is actually created, and culminates in the periods immediately preceding the launch of the pool. This expectation is based upon the assumption that patent holders would prefer being among the founding members of a pool, rather than having to negotiate entry with incumbent members. We have provided empirical support for this assumption in Chapter 2. Based upon this hypothesis, Dequiedt and Versaevel (2012) also predict that expected patent pool creation induces companies to overall anticipate their investment in related R&D. Our empirical findings are thus fully consistent with the predictions of the theoretical literature on the effects of prospective pool creation on ex-ante incentives to invest in related R&D and patenting.

It should however be stressed that our findings are limited by the fact that we do not directly observe firms' expectations with respect to future pool creation. We only observe actual pool creation on some standards, and assume that at least some firms expected pool creation for these standards with a higher likelihood than for other standards released at the same time. In future work, it should be analyzed whether our findings are robust if we explicitly model expectations as a function of observable standard characteristics in conjunction with learning about the conditions for successful pool creation.

5. Conclusion

In this article, we have analyzed how standard-related patenting and declarations of essential patents are affected by the known possibility to create a patent pool. We show that the change in competition policy has strongly altered the chances for the successful creation of a patent pool. We provide evidence that patent declaration as well as firm individual patenting show unusually high levels around the launch of a standard-related pool. There is an important difference between standards released before and after the policy change. While patenting is especially high before the pool is launched for the most recent standards, we find a direct effect right after pool creation for standards released before 1999. These findings indicate that companies were less able to anticipate pool formation before 1999, when patent pools were still subject to legal uncertainty. Today, patent pools are commonly accepted by antitrust authorities and several successful pools set an example for well-functioning mechanisms for pooling patents. Firms are thus able to include the possibility of a pool formation in their expectations of future returns on patents.

Our findings overall support the argument that patent pools have a positive effect on patenting. However, our analysis of the increasing number of patent declarations points out that patent pools have contributed very little to this increase. Most patent declarations are declared to standards that do not qualify for pooling patents. Still, policy makers should take into account that firms' incentives to patent may change due to a pool creation.

However, our analytical framework does not allow us to conclude whether this incremental patenting reflects an increase in substantial innovation or opportunistic patenting. The theoretical proposition that an increase in the expected value of patents leads to more R&D investment rests upon the assumption that firms cannot easily adapt their patent propensity. Given the importance of strategic patenting in the field of ICT standards, we would not be confident to interpret increases in the number of patents as evidence of an increase in substantial innovation. Further empirical research using outside measures of technological progress is required to analyze this question.

To guide this future research, our findings have pointed out that innovation measures need to take into account the role of expectations. We have made the case that in order to analyze substantial effects on innovation, researchers should focus upon the R&D investment incurred preceding expected or at least foreseeable patent pool creation. Our information on expectations concerning pool creation is however limited to the policy change. A challenge for future research is to better measure firms' expectations concerning pool creation, which may also depend upon prior experience with pools, market constellations, licensing strategies and implicit or explicit agreements between firms.

Chapter IV : Joint innovation in ICT standards : How consortia drive the volume of patent filings

L'innovation commune dans les standards des NTIC: comment les consortia influencent le nombre de brevets déposés

Le développement de standards technologiques dans les nouvelles technologies d'information et de communication (NTIC) est une forme légère d'innovation collaborative : les firmes développent dans un premier temps des technologies rivales, parmi lesquelles certaines technologies seront par la suite sélectionnées pour faire partie d'un standard. Dans ce contexte, des firmes utilisent souvent des consortia informels qui prennent les devants et précisent une feuille de route pour la suite du processus de standardisation. Cet article évalue comment de tels consortia influencent le nombre de brevets déposés autour des standards technologiques, et analyse si cet effet est socialement efficace. Nous montrons que l'effet des consortia dépend du rapport de forces entre les différentes incitations des firmes à développer le standard. Le fait d'être membre d'un consortium induit une augmentation du nombre de brevets déposés si la rémunération des brevets essentiels est insuffisante et les firmes sous-investissent dans le développement du standard. Cet effet est toujours socialement efficace. Dans des situations où la rémunération des brevets essentielles est excessive et incite à des courses aux brevets, le fait d'être membre d'un consortium n'induit qu'une faible augmentation ou même une baisse du nombre de brevets déposés. Au moins dans le cas d'une baisse, l'effet du consortium sur l'efficacité est également positif.

1. Introduction

Over the past twenty years, the number of essential patents claimed on ICT standards has strongly increased (Simcoe, 2007). This evolution firstly denotes the importance of these patents for firms: they can generate substantial licensing revenues, and be used as bargaining chips to obtain freedom to operate on rivals' patent portfolios (Rysman & Simcoe, 2008). Another explanation lies in the growing complexity of ICT standards. As compared with other sectors, standardization in ICT has indeed evolved from the definition of mere specifications enabling interoperability to the joint development of large technology platforms including critical technologies . Consequently, they tend to embody a growing number of patented components.

While the conditions for licensing essential patents have been widely discussed (see e.g., Shapiro, 2001; Lerner & Tirole, 2004; Layne-Farrar & Lerner, 2011), the peculiar type of collaborative innovation they proceed from has received less attention so far. Formal ICT standards are developed in standard setting organizations (SSOs)–such as ETSI (telecommunications) or IEEE (electronics)–that are open to a broad range of stakeholders. Besides the large number of participants, the originality of this process is that it does not involve any ex ante contracting between the firms preparing to develop a standard (Ganglmair & Tarentino, 2011). The choice of standard specifications rather takes place ex post in ad hoc working groups, based on the merit of rival technologies available to solve a given technical problem. Firms thus compete in R&D ahead of the working group meetings, thereby generating a large volume of patented innovations of which only a fraction will eventually become essential.

This formal process generates costly R&D cost duplications and delays due to vested interests (Farrell & Simcoe, 2012; Simcoe, 2012). Firms therefore increasingly rely on informal consortia to take the lead in the standard setting process (Cargill, 2001; Lerner & Tirole, 2006). Such consortia are fora wherein a group of firms seek to agree on a common design that they will jointly push as a standard. While some of them substitute for the lack of formal SDOs and issue their own standards (e.g., Blu-Ray alliance or W3C for web protocols), most consortia actually accompany formal standardization . They are then a means for members to better focus their R&D investments on a common roadmap (Delcamp & Leiponen, 2012), thereby saving useless development costs while enhancing their chances to obtain essential patents (Pohlmann and Blind, 2012). Leiponen (2008) furthermore shows that participation in a consortium improves the capacity of firms to influence the technological decisions taken at the formal SSO.

This paper aims to assess how such consortia influence the volume of patents filed around formal standards, and whether this is efficient. We show that their effect actually depends on the strength of firms' incentives to develop the standard. Consortium membership induces a higher number of patent files in situations where insufficient rewards for essential patents induce underinvestment in the standard. This effect is necessarily pro-efficient. In situations where excessive rewards induce patent races, consortium membership only moderately increases or even reduces their volume of patents. At least in the latter case, the effect of consortia membership is also pro-efficient.

The implications of these results are twofold. They first highlight the cost entailed by the loose coordination of R&D investments in formal SSOs. In this context, they also suggest that the creation of informal consortia can be an efficient way to supplement formal SSOs. Consortia are indeed an effective means to unlock the development of standards when firms have insufficient incentives to contribute technology, while they do not significantly amplify the race for essential patents when these incentives are strong.

The paper proceeds in two steps. We first develop a theoretical model to analyze the efficiency of distributed innovation into a standard. We then assess empirically the actual impact of consortia over a large panel of ICT standards.

Our model allows for some degree of rivalry between the firms' innovations, so that only a fraction of their patents eventually become essential. We firstly establish that the level and efficiency of firms' investments depend on the share of the standard's value that accrues to owners of essential patents. A public good pattern involving sub-optimal investment prevails in equilibrium when the licensing revenue of essential patents holders is not sufficient to cover their R&D costs. Conversely, firms engage in a wasteful patent race when licensing profits exceed total R&D costs.

Against this background, we introduce consortia as a means to mitigate technology rivalry between member firms. By joining a consortium, a firm may thus deflate its volume of patents by cutting irrelevant R&D investments, or inflate it by seeking to develop more relevant innovations. We show that consortium membership is always pro-efficient if the first effect dominates. A patent-inflating consortium is also pro-efficient in a public good equilibrium, but it may actually harm efficiency in a patent race equilibrium if it induces an excessive inflation of patents around the standard.

Drawing on this framework, we use a large panel of ICT standards to assess the actual effect of consortia empirically, respectively for standards entailing over- and underinvestment. For this purpose, we have developed an original dataset of standard-related patent applications at firm level, which we use as a proxy for firms' R&D investments. We also use information on the participation of pure R&D firms in the standard development process in order to identify over-investment patterns. We find that firms entering a consortium strongly increase their patent files in most of the cases. This is however not true for standards featuring an over-investment pattern: in these cases, consortia membership has a smaller, and in some cases negative effect on firms' patent applications. These results thus suggest that consortia tend to enhance the efficiency of innovation in the development of standards.

The remainder of this article is organized as follows. We present the theoretical model and its implications in Section 2. Section 3 discusses the empirical strategy, the database and econometric results. We conclude in Section 4.

2. Theoretical framework

2.1 Value of the standard

We consider a set *N* of *n* firms that take part in the development of a standard. The standard embodies $x = \sum_{i \in \mathcal{N}} x_i$ essential patents contributed by the firms, and its implementation is expected to generate aggregate profits $v(x)$ in the industry. These profits increase with the amount of embarked technology, but with decreasing returns: $v'(x)>0$ and $v''(x)<0$[68].

There are two ways in which firms can derive revenues from the standard. Patent holders firstly appropriate a share $r \in [0,1]$ of the standard's value through the royalties they charge to implementers of the standards. Parameter *r* can thus be thought of as reflecting the IP licensing policy of the standard setting organization (*r=0* denoting a royalty free policy). In line with common practices regarding ICT standard, we assume that the share of the licensing revenues that accrues to firm *i* □□*N* is proportional to its share of the essential patents (x_i/x).

The remaining part of the revenues, $(1-r)v(x)$, accrue to the firms that implement the standard in their products. Let s_i denote firm *i*'s share of these revenues, which can be

[68]These assumptions account for various possible specifications. The standard's value *v* (.) can in particular reflect a dynamic innovation process, if we define it as the expected outcome l*x*p/ (d+l*x*) of a Poisson process whith hit rate □*x*, discount rate □, and aggregate profits □.

thought of as its share of the market for standard-compliant products. We assume that all firms with s_i>0 are involved in the standard setting process (so that $\sum s_i = 1$). Other firms (s_j=0) may also contribute patented inventions provided they have appropriate R&D capabilities, but they will get a return only through royalty revenues. Taking into account both sources of profits, the expected benefit of firm $i \in N$ is thus:

$$B_i = v(x)\left[r\frac{x_i}{x} + (1-r)\,s_i\right]$$

2.2 R&D investments

The definition of a standard is the outcome of an open innovation process wherein firms submit innovations, some of which only will be included in the standard specifications. Assuming constant and symmetric per unit R&D costs *c*, the R&D cost function of firm $i \in N$ is proportional to y_i, the number of patents it develops for the standard:

$$C_i = cy_i$$

Equation (1) in turn posits that only a fraction of these patents eventually become essential.

$$\frac{x_i}{y_i} = \gamma_i \in (0,1) \qquad (1)$$

Firm *i*'s *selection rate* γ_i denotes the chance that one of its patented inventions be eventually included in the standard specifications. Conversely, γ_i^{-1} measures the number of patents that firm *i* must develop in order to obtain one essential patent. We define *technology rivalry* between the firms as follows:

$$m = \sum_{i \in \mathcal{N}} \gamma_i^{-1} \geq n \qquad (2)$$

This parameter can be interpreted as a measure of the degree of complementarity or substitutability between the firms' innovations. Setting *m*=*n* implies in particular that the firms' innovations are perfect complements: each of them can be adopted without evicting another one. More generally, the ratio *m*/*n* provides us with a measure of the degree of rivalry between the different technology alternatives promoted by the firms. For instance, a ratio *m*/*n*=10 means that only one out of ten innovations developed for the standard will become essential. At the firm level, observe finally that firm *i* has a relatively weak position vis-à-vis other firms if $g_i < n/m$.

2.3 Public good or patent race

We first highlight two types of coordination failure that may prevail in this context. Each firm *i* □□*N* defined by $\{\gamma_i, s_i\}$ makes its investment decision so as to maximize B_i-cy_i. Solving this problem over x_i yields the first order condition below:

$$v'(x)\left[r\frac{x_i}{x}+(1-r)\,s_i\right]+rv(x)\,\frac{x-x_i}{x^2}=\frac{c}{\gamma_i} \qquad (3)$$

The term in brackets captures the public good nature of the standard. It implies that firm *i*'s direct incentive to develop the standard is proportional to the share of the value it can appropriate. The second term captures a patent race effect: To appropriate part of the expected profit, firm *i* needs to invest more the higher the number of essential patents held by its R&D competitors. It is easy to check that the LHS of equation (3) is decreasing in *x*, so that the firms' decisions are strategic substitutes. Summing the FOC of all firms *i*=1, *n*, we derive the joint R&D investment x^* in equilibrium.

$$\frac{1}{n}\left[v'(x^*)+rv(x^*)\,\frac{n-1}{x^*}\right]=c\frac{m}{n} \qquad (4)$$

The aggregate marginal profits (LHS) again combine the properties of a public good investment (marginal benefits are diluted when the number of firm increases) and a patent race (when *r*>0, extra incentives are stronger the larger the number of competitors). On the RHS, the aggregate marginal cost of essential patents is higher when *technology rivalry* is strong (large *m*/*n*).

Observe also that the aggregate marginal cost does depend on the distribution of the g_i between the firms, but only on the degree of technology rivalry at the aggregate level (*m*/*n*). We use this property to study how the structure of the incentives affects the efficiency of firms' investments. Let us consider a social program wherein a unique representative firm with *selection rate* $\overline{\gamma}=\left(\frac{m}{n}\right)^{-1}$ maximizes aggregate profits:

$$\max_x \Omega = v(x) - cx/\overline{\gamma}$$

Comparing the outcome of this program with the equilibrium outcome, we can establish the following result.

Proposition 1 *Aggregate investment in equilibrium is efficient if the licensing revenues* $rv(x^*)$ *equals the total R&D cost* $cx^*/\overline{\gamma}$. *Firms invest in excess if licensing revenues exceed total cost and they underinvest in the reverse case.*

Firms' incentives to innovate can induce either too much (patent race pattern) or too little (public good pattern) investment. Which one prevails in equilibrium depends on the balance between total licensing profit and the total R&D cost at equilibrium. Firms engage a patent race if

$$rv(x^*) > \frac{cx^*}{\overline{\gamma}} \tag{5}$$

Intuitively, a patent race takes place when licensing is profitable per se, so that firms will compete in R&D in order to preempt the essential patents. Conversely, the public good equilibrium emerges when firms' incentives are primarily driven by the possibility to use the standard. Observe that condition (5) also implies that the participation of a pure R&D firm *i* (s_i=0) with average success rate $\gamma_i = \overline{\gamma}$ is profitable only in a patent race equilibrium:

$$(5) \quad \Leftrightarrow \quad \frac{x_i^*}{x^*} rv(x^*) - c\overline{\gamma} x_i^* > 0 \tag{6}$$

Corollary 2 *The participation of pure R&D firms signals a patent race pattern in equilibrium.*

We will use this result in the empirical section to infer the existence of a patent race equilibrium from the participation of pure R&D firms. We can finally observe that the number of firms does not determine the type of equilibrium that prevails, but its magnitude. Hence Proposition 1 and its corollary are robust to allowing free entry of firms in the standardization game.

Corollary 3 *The inefficiency pattern prevailing in equilibrium does not depend on the number of firms, and is thus robust to free entry.*

2.4 Efficiency of consortium membership

Recall that the consortia we are interested in do not involve any formal contracting or joint R&D decisions. They rather function as fora wherein participating firms seek to agree on a mutually acceptable roadmap for specifications that they will jointly push in the SDO. Accordingly, we posit that consortium members can better focus their R&D effort, thereby saving useless investments and enhancing their chances of obtaining essential patents.

Assuming that a subset of firms *K* □□*N* have created a consortium to support the standard setting process, members thus benefit from a higher selection rate[69]: $\gamma_{k\in\mathcal{K}} > \gamma_{k\in\mathcal{N}\setminus\mathcal{L}}$ where $\mathcal{L} = \mathcal{K}\setminus\{k\}$.

We focus on the consequences of firm *k*'s decision to join the consortium[70]. Formally, this firstly translates into a positive shock on the new member's selection rate (dg_k>0). Since firm *k* can better screen irrelevant innovation opportunities, this in turn induces a fall in the degree technology rivalry at the aggregate level: $dm/d\gamma_k = -\gamma_k^{-2}$. It thus follows directly from (4) that the number of essential patents embodied in the standard increases in equilibrium. Since the firm's decisions are strategic substitutes, it is moreover clear from (3) that firm *k* develops more essential patents while the other firms react by developing less of them. Lemma 4 summarizes these results.

Lemma 4 *Joining the consortium enables the new member to develop more essential patents in equilibrium, while the other firms develop less essential patents. The net effect is positive, and thus induces an increase of the equilibrium value of the standard v* (x^*).

This result does not necessarily imply that an enlarged consortium coalition is efficient, since it does not take into account the induced variation of firms' R&D costs. Indeed, deriving firms' aggregate profits $\Omega = v(x^*) - c\sum_i x_i^*/\gamma_i$ with g_k and rearranging makes it possible to highlight the following three effects:

$$\frac{\partial\Omega}{\partial\gamma_k} = \underbrace{\frac{cx_k^*}{\gamma_k^2}}_{A} + \underbrace{\frac{\partial x^*}{\partial\gamma_k}\left[v'(x^*) - \frac{c}{\bar{\gamma}}\right]}_{B} + \underbrace{c\sum_i \frac{\partial x_i^*}{\partial\gamma_k}\left[\frac{1}{\bar{\gamma}} - \frac{1}{\gamma_i}\right]}_{C} \qquad (7)$$

The first effect corresponds to R&D costs savings induced by firm *k*'s ability to reduce the volume of non-essential patents (*A*). It is clearly positive. The second one is the net (cost/benefit) value of adding new essential patents to the standard (*B*). It is clear from the

[69]We implicitely assume here that the size of the consortium coalition does not change the success rate of former members or consortium outsiders. In other words, the only effect of consortium membership is a better access to information of future specifications. The entry of a new member in the coalition nevertheless indirectly affects former members and outsiders through the new member's stronger ability to preempt essential patents in the standard.

[70]In practice, firms have to pay significant membership fees to join consortia, and therefore decide to do so only if they have significant stakes in the standard. The benefits in terms of information and influence strongly depend on idiosyncratic factors such as the degree of compatibility between the firms' technology profiles and strategic agenda.

term in brackets that it is positive in a *public good* equilibrium. Indeed new patents can then mitigate firms' lack of investment in the standard. By contrast, developing more essential patents reduces joint profits in a *patent race* equilibrium. Finally, the third effect captures the cost or benefit of reallocating the development of essential patents between the firms (*C*). Its sign may be positive of negative, depending on the selection rate of firm *k* as compared with the other firms. Lemma 5 summarizes these findings.

Lemma 5 *A firm's entry in the consortium deflates the volume of non-essential patents, which is clearly efficient. By contrast, the inflated volume of essential patents may be inefficient if i) a patent race pattern prevails in equilibrium and/or ii) it entails a reallocation of R&D effort from efficient to inefficient firms.*

In order to carry further the analysis, we now focus on the direct effects of firm *k*'s patenting strategy on joint profits, aside from the other firms' reactions[71]. We are especially interested in relating joint profits with the (empirically observable) total volume of patents filed by firm *k*. Assuming that firm *k* has average selection rate $(\gamma_k = \overline{\gamma})$, we can establish that

$$\frac{cx_k^*}{\gamma_k^2} + \frac{\partial x_k^*}{\partial \gamma_k}\left[v'\left(x^*\right) - \frac{c}{\overline{\gamma}}\right] > 0 \quad \Leftrightarrow \quad dy_k^* < \Delta \frac{dx_k^*}{\overline{\gamma}}$$

where

$$dy_k^* = \frac{dx_k^*}{\overline{\gamma}} - x_k^* \frac{d\overline{\gamma}}{\overline{\gamma}^2} \tag{8}$$

is the variation of the total number of patents filed by firm *k* (that is, the difference between the volumes of spared patents and new essential patents) and $\Delta = \overline{\gamma} v'\left(x^*\right)/c$. Since □□> 0, condition (8) clearly holds if the total volume of firm *k*'s patents is deflated. This is quite intuitive, since firm *k* then develops more essential patents and saves at the same time the R&D cost of an even larger volume of useless patents.

The effect of firm *k*'s move is more ambiguous if joining the standard has a patent inflating effect. Indeed the benefit of enhancing the standard's value must then be balanced with the cost of a larger volume of patents. As stated in Proposition 6, the new member still invests more efficiently provided the *public good* pattern prevails in equilibrium. Indeed, it thereby provides more of the missing essential patents, and it does so at a lower cost thanks to consortium membership. By contrast, and inflated volume of patents filed by the new member may harm efficiency in a *patent race* pattern, unless the volume of extra non-

[71]This can also be interpreted as an approximation of the full effects when the reactions of the other firms are negligible. We will see in the next section that this interpretation is actually supported by empirical evidence.

essential patents remains sufficiently small to be compensated by the benefit of new essential patents.

Proposition 6 *Assume that a firm with average success rate joins the consortium:*

- *A deflated volume of patents filed by the new member is efficient whatever the inefficiency pattern prevailing in equilibrium.*
- *A inflated volume of patents filed by the new member is efficient in a public good equilibrium. It becomes inefficient in a patent race equilibrium when it exceeds a positive threshold* $T \in (0, dx_k^*/\overline{\gamma})$.

Proof. Observe also that $\Delta > 1 \Leftrightarrow v'(x^*) - v'(x^*) - c/\overline{\gamma} > 0$, which is the condition for the *public good* pattern to prevail in equilibrium. Since $dy_k^* < dx_k^*/\overline{\gamma}$, it directly follows that condition (8) is also verified in a *public good* equilibrium when firm *k* inflates its volume of patents. By contrast, the *patent race* pattern prevails when 0 < □□< 1. Hence joint profits can increase only if the inflation of firm *k*'s patents remains moderate, that is if $dy_k^* < T \in (0, dx_k^*/\overline{\gamma})$. Otherwise, a strong inflating effect induces a fall of joint profits.

3. Empirical analysis

This section in turn presents an empirical analysis of patent filings around a large panel of ICT standards. Our purpose is to assess whether joining a consortium changes the volume of patents filed by firms involved in standard development, and what is the direction of this change. Drawing on the results of our theoretical analysis, we assess this effect separately for standards corresponding respectively to a *public good* or *patent race* pattern.

3.1 Data and indicators

Our empirical analysis draws on a comprehensive dataset of technological standards including essential patents[72]. Our sample includes all ICT standards issued between 1992 and 2009 by one of the major formal SSOs which operate on an international level[73]. Since we aim to focus on the interaction between formal standardization and companion consortia,

[72] A summary of all relevant variables with description and sample statistics can be consulted in Appendix 1

[73] ISO, IEC, JTC1 - a joint committee of ISO and IEC -, CEN/CENELEC, ITU-T, ITU-R, ETSI, and IEEE.

we exclude standards that are exclusively developed by informal standards consortia (e.g. BluRay).

We furthermore restrict the analysis to standards including essential patents of at least two different companies, thereby limiting the sample to 578 standards. Companies that own IPRs which are essential to a standard provide this information to the respective SSO. We downloaded these patent declarations at the websites of the above-mentioned SSOs in March 2010. From the PERINORM[74] database we retrieve information on the date of first release, releases of further versions and amendments, number of pages from the standard document such as the technical classification of the standard.

Our sample includes 242 different companies declaring essential patents, observed over the whole period. For each firm, we collect yearly information on the amount of sales, R&D expenditure, employees and market to book ratio (Tobin's Q[75]). In addition we distinguish between pure R&D firms, manufacturer and net provider[76] and classify our sample by main active industry using SIC codes.

We connect the firm level data to the specific standard information and built up a panel of 1,720 company-standard pairs observed over a time span of 18 years (1992-2009). For each company-standard pair, we observe the amount of patents filed by the respective company in the technological field for the respective standard, and include a dummy variable indicating whether the company takes part in a consortium supporting the development of this standard. Other time-variant control variables are either company- or standard-specific. Time-invariant factors affecting the firm, the standard or the relationship between both are captured by company-standard pair fixed effects.

3.1.1 Matching between informal consortia and formal standards

To identify informal consortia accompanying the formal standardization process, we use data from 15 editions of the CEN survey of ICT consortia and a list of consortia provided by Andrew Updegrove. We identify approximately 250 active ICT consortia[77]. We categorize these consortia as to industry, function (spec producer, promoter) and years of activity (see Appendix 1). The connection to a standard in our sample is analyzed by using liaison agreements and information from consortia and SSO web pages. For instance, a connection

[74] PERINORM is the world's biggest standard database with bibliographic information on formal standards and is regularly updated by the SDOs DIN, BSI and AFNOR.
[75] We used the Thomson one Banker database to match the respective firm level data.
[76] We used the extended business model description in the Thomson One Banker database and compared our classification to the list of companies identified by Layne-Farrar and Lerner (2010).
[77] This is coherent with the identification of the CEN survey which reports approximately 250 standards consortia in ICT.

was identified, when a consortium explicitly references a formal standard, or when a standard has been submitted to the formal SSO by an informal consortium. We are conservative in establishing the connections, resulting in a narrow list of 54 consortia. We use supplementary information for the selected consortia and further restrict the list to 21 consortia that technologically (spec producer) and significantly contribute to this specific standard (excluding pure promoting consortia)[78]. Using information on the websites of the consortia as well as internet archives (www.archive.org) and internet databases (www.consortiuminfo.org), we inform consortium membership over time and connect this information with the company standard pairs of our sample.

3.1.2 Standard specific patents

The most intuitive approach to track firms' R&D investments in standards is to count the patent declarations they state for these standards. However, former empirical analyses have shown that the timing of declaration is not connected to the dynamics of standardization (see Chapter 3). Moreover essential patents only represent a very small amount of patenting around standards (Bekkers et al., 2012). To avoid these shortcomings, we thus build up a new measure of firms' standard-specific R&D investment. In a first step we count patents filed from 1992 to 2009 by the companies in our sample at the three major patent offices (USPTO, JPO and EPO), using the PatStat database and the company assignee merging methods of Thoma et al. (2010). We restrict the count of patent files to IPC classes in the relevant technological field of each standard, identified by using the IPC classification of declared essential patents[79]. We measure the dynamics of patenting over the standard lifecycle (details can be consulted in Appendix 3). Our mean value analysis shows a patenting increase before standard release and a decrease thereafter. This finding reassures us that our variable captures the innovation for a specific standard, which indeed is expected to culminate in the period immediately preceding standard release.

[78]Assisting this rather broad distinction we conduct a word count analysis on the consortia self-description abstracts, kindly provided by Andrew Updegrove. We use keywords such as "developing", "creates", "set standard" or "standardizes". Appendix 1 provides a list of those consortia and standards for which a link could be established, as well as the narrower list of consortia contributing technologically.

[79]This method is a novel way of measuring standard-specific R&D investment. We apply tests of timing, estimate technological positions of standards as well several test of size measures to prove our proposed variable to be a sufficient indicator of standard-related R&D investment. The methodology and the various tests have been presented at the Patent Statistics for Decision Makers Conference 2011 at the USPTO and can be reviewed in Appendix 3.

3.1.3 Public goods and patent race patterns

One contribution of our analysis is the comparison of over- and under investment in standardization. As shown in the theoretical model, the *patent rac*e pattern can be identified when pure R&D firms take part in the standard development. We use this prediction as our identification strategy for the empirical sampling of standards. By labeling over- and underinvestment as to the classification above, we compare the residual results of a regression of standard related patent files against technical characteristics of the standards (details can be consulted in Appendix 4). A t-test analysis suggests that our classification of overinvestment is an appropriate measure. Results show that residual values of the regression are in average positive for standards where pure R&D firms participate to a standard and in average negative for those where pure R&D firms are not involved.

3.2 Descriptive statistics

3.2.1 Pairwise correlations

In the following Table 1, we provide pairwise correlations of firm-specific, standard-specific and firm-standard-specific variables at the company-standard-pair level. The volume of patents around standards is negatively correlated with both consortium membership and the existence of a consortium on the standard. This could indicate that consortia attract companies with smaller standard-related patent portfolios. On the other hand, consortium membership is positively correlated with the value of sales and the number of employees. The existence of consortia is positively correlated with the number of firms per standard and with standard age. As to the correlation analysis effects are yet not strong enough to derive conclusive interpretations.

		1	2	3	4	5	6	7	8	9
1	St. R&D Invest.	1								
2	Member	-0.10	1							
3	Consortia Exists	-0.14	0.67	1						
4	Standard Event	-0.07	0.39	0.58	1					
5	Tobin's Q	0.02	0.01	-0.04	-0.05	1				
6	Sales	0.11	0.06	0.01	-0.01	-0.25	1			
7	Employees	0.10	0.06	0.01	0.02	-0.33	0.87	1		
8	Number of Firms	0.05	0.34	0.60	0.62	-0.09	-0.02	0.00	1	
9	Standard Age	-0.07	0.17	0.29	0.32	-0.20	0.00	0.05	0.25	1

N= 1,046, All correlation coefficients above |0.2| are significant at $p < 0.05$.

Table 1: Pairwise correlations on the company-standard level

3.2.2 Difference in means

In the following Table 2, we present differences in the volume of patents, the number of employees, the value of sales and the book-to-market ratio between consortia member observations and the rest. Membership observation is associated with a lower volume of standard-specific patents, but a higher number of employees and a higher value of sales.

t = 4.1256			**Standard Specific Patent Files**			
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	261	2,238.6	190.8	3,081.9	1,862.9	2,614.2
not consortium members	1,571	12,092.8	972.8	38,559.2	10,184.6	14,001.0

t = -2.4585				**Employees**		
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	272	125,635.0	6,929.8	114,289.8	111,991.9	139,278.2
not consortium members	1,645	106,528.7	2,945.1	119,448.5	100,752.2	112,305.2

t = -2.6035				**Sales**		
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	272	40,119.1	1,774.0	29,257.4	36,626.5	43,611.6
not consortium members	1,644	35,211.2	708.4	28,721.6	33,821.8	36,600.6

t = -0.2502			**Book-To-Market Ratio**			
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
consortium members	243	1.7	0.1	1.5	1.5	1.9
not consortium members	1,240	1.7	0.0	1.4	1.6	1.8

Table 2: Differences in variable means between consortia members and others

3.3 Multivariate analysis

3.3.1 Estimation methodology

We use our panel dataset to estimate how consortium membership affects the volume of patents filed around the related standard. Our dependent variable is the number of patent priority filings by firm *i* for standard *j* in year *t*. Our first key explanatory variable, $member_{ijt}$, is a dummy equal to one for years where the firm *i* participates in a consortium supporting standard *j*. Following the theoretical model, we expect its effect to depend upon whether the standard is initially characterized by over- or underinvestment. We therefore interact the consortium membership dummy with the $over\_investment_j$ variable, denoting the share of pure R&D firms involved in the development of standard *j*.

To account for unobserved heterogeneity of standards and companies, we systematically include fixed effects for company-standard pairs. As our dependent variable is a count variable with overdispersion with respect to a poisson distribution, we will use a poisson estimator with robust standard errors unless explicitly stated otherwise[80]. We furthermore cluster standard errors by companies in order to exclude that unobserved shocks to a company's patenting level bias the standard errors and lead to an insufficiently restrictive confidence interval[81]. Unsurprisingly, we found strong evidence for persistent effects of transitory shocks to our explained variable, as indicated by positive autocorrelation of standard errors. We therefore include the lagged dependent variable as explanatory variable in all models. Our basic regression model has the following specification:

$$\begin{aligned} st\_patents_{ijt} \quad = \quad & \exp\left(\alpha_1 . st\_patents_{ijt-1}\right. \\ & +\beta_1 . member_{ijt} \\ & +\beta_2 . member_{ijt} * over\_investment_j \\ & +\beta_3 . st\_activity_{jt-1} \\ & \left. +F'_{it-1}\beta_4 + X'_t\beta_5 + c_{jt} + \varepsilon_{ijt}\right) \end{aligned}$$

where $st\_activity_{jt\text{-}1}$ counts version releases and amendments per year, $F_{it\text{-}1}$ is a vector of firms specific change such as a measure of Sales and Tobins's Q, $X_{jt\text{-}1}$ denotes other control variables for time trends such as the overall ICT patent files and the count of patent declarations, c_{jt} are standard age dummies and e_{ijt} is an idiosyncratic error term.

[80]We prefer the poisson estimator with robust standard errors over a negative binomial estimator with fixed effects, because the negative binomial estimator cannot totally control for fixed effects and thus account for unobserved heterogeneity.

[81]All presented results are robust to clustering standard errors by standard instead of by company.

We use the standard age dummies, each indicating a one year period in the standard lifetime, to control for the timing of standardization. Downstream innovation and patenting (taking place after the first release of the standard) is indeed likely to peak around periodical revisions of standards. The release of new standard versions or amendments to existing versions is labeled as standard activity and included as a control variable. In order to exclude immediate feedback (amendments or version releases explained by prior innovation), we include this control variable with a one-year lag.

We furthermore wish to account for external shocks such as the business cycle or technology-related policy. As we already control for standard fixed effects and standard age, it is impossible to include year dummies as a further control because of a collinearity problem. We therefore control for external shocks by including the overall number of triadic patent priorities filed per year in the relevant technological category (respectively IPC class G for telecom and IPC class H for IT standards) and the overall number of patent declarations made to any formal ICT standard per year in order to capture policy shocks that are more specifically relevant to essential patents.

3.3.2 Estimation model 1-4

Consortia are more likely to be created for important or technologically complex standardization projects. Furthermore, the organization of R&D can be different if a consortium is created for a standard. For these reasons, the timing of standardization is likely to be affected by the existence of consortia. It is thus preferable to estimate all coefficients, including controls for standard timing, only on the sample of standards related to an informal consortium. This strategy could however bias downwards the estimated effects of consortia, if some of these effects are systematically captured by control variables. We therefore present results based upon the whole sample in model M1. As expected, the coefficients on consortia variables are higher in the larger sample, but the fit of the model is much lower. This indicates that heterogeneity between standards with consortia and other standards is large. We therefore only estimate standard with accompanying consortia in all following models (M2-M4), while acknowledging a potential downward bias on our consortia coefficients.

In our second model (M2), consortium membership has a significant positive effect on the volume of standard-specific patents, but the level of this effect decreases with the level of overinvestment. This result is however potentially subject to an endogeneity bias. Unobservable variables, such as changes in the strategic importance of the standard for the specific company, may have an impact on both standard specific patents and consortium membership. External factors jointly affecting consortium membership and related patenting are particularly likely to occur in periods of turmoil, like the internet bubble in 2001. While desirable in order to reduce within-groups bias on weakly endogenous variables (Nickell, 1981; Bloom et al., 2010), the long period of observation (relatively to the fast-evolving world of ICT standards) increases the vulnerability to this type of biases.

Unit of Observation = Company Standard Pair DV = Standard Specific R&D Investment (Patent Files)										
	M1		M2		M3		M4		M5	
	Coef.		Coef.		Coef.		Coef.		Coef.	
Member	0.470	***	0.208	**	0.188	*	0.193	**	0.194	**
	(0.175)		(0.108)		(0.105)		(0.098)		(0.077)	
Member * Over Investment	-1.746	***	-1.135	*	-1.172	*	-1.203	*	-1.349	***
	(0.981)		(0.636)		(0.705)		(0.685)		(0.506)	
Lag1 Standard Activity	-0.061	*			-0.022	***	-0.022	**	-0.021	**
	(0.032)				(0.008)		(0.008)		(0.009)	
Lag1 Patent Files[1]	0.002	***	0.072	***	0.044	**	0.04	*	0.022	**
	(0.001)		(0.017)		(0.021)		(0.022)		(0.004)	
ICT Patent Files[1]	0.003	**	0.007	***	0.006	**	0.007	**	0.008	***
	(0.002)		(0.001)		(0.003)		(0.003)		(0.003)	
Patent Declarations[1]	-0.001		-0.003		0.002	***	0.004		0.008	
	(0.006)		(0.006)		(0.009)		(0.01)		(0.009)	
Lag1 Tobin's Q									0.088	
									(0.059)	
Lag1 Sales[1]									-0.011	***
									(0.003)	
Standard Year Dummies	Incl.		Incl.		Incl.		Incl.		Incl.	
Log Likelihood [2]	-17.82		-490.8		-68.55		-59.35		-114.1	
AIC [2]	35,600		981		137		118		228	
BIC [2]	35,600		981		138		118		228	
Observations	16,390		4,181		999		884		884	
Groups	1,046		298		174		158		158	

Note: All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. Model 2-4 are restricted to a limited time period 2002-2009. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.

Table 3: Results of the multivariate analysis – testing consortia membership (firm level)

In order to deal with these concerns we restrict the observation period to 8 years from 2002 to 2009. Furthermore, we also reduce the cross-section dimension of the panel, by restricting the sample to stock-market listed companies. These companies are more likely to react in a similar fashion to external events. Finally, we identify positive or negative shocks to the number of employees in a one year period[82], indicating mergers, acquisitions, restructuring etc. If this shock takes place after 2005, all observations after the shock are dropped for this company, if the shock takes place earlier, we drop all previous observations. Companies with more than one shock are dropped altogether for our third model (M3), reducing the sample to 174 groups and 999 observations.

In our last model M4 we furthermore tackle endogeneity more directly by including time-varying firm characteristics as control variables. We choose to include the value of sales, and Tobin's Q as a measure of expected profits (both lagged by one year to exclude immediate feedback). We opt for not including employees, which is highly correlated with sales in the within dimension (both reflecting company growth). Furthermore, the number of employees, with respect to the value of sales, is likely to be more important for determining whether a company has the possibility to participate in a consortium, but less important in independently determining the evolution of patenting[83]. By including the value of sales as a control, we nevertheless face the risk to bias downwards the estimates of the consortia effects for smaller companies refraining from joining an expensive consortium. We therefore divide the level of consortia member fees[84] by the value of sales of the company at the time of consortium creation. The first percentile of observations according to this value (the companies-standard pairs characterized by the highest consortia fees relative to the value of sales) is most at risk to be affected by this effect. We therefore decide to exclude these observations, leaving us with 158 company-standard pairs and 884 observations in model 4. M1-M4 show robust results. The magnitude of the coefficients decreases but the effects are yet more significant, and the signs of the coefficients are unchanged.

3.3.3 Robustness

We check for robustness of our results to a correlation of our main explanatory variables with past outcomes of the dependent variable. It is plausible that a company's decision to join a consortium depends upon its stock of related patents. In this case, the regressors are

[82]distribution, the lower 5% are labeld as negative shocks.

[83]The primary cost of consortium participation is workload, while the cost of patenting is primarily financial

[84]Since our goal is to estimate the financial burden to join a consortium we use the low range of membership fees (find an overview of highest and lowest membership fees in the appendix 1).

predetermined, and the poisson fixed effect estimator yields inconsistent results (Blundell et al., 1999). In order to account for this problem, we take advantage of the fact that we have information on pre-sample levels of our dependent variable and adopt the methodology suggested in Blundell et al. (1999), substituting pre-sample means for fixed effects. The results displayed in Appendix 5 are mainly consistent with the results from the fixed effect analysis.

3.3.4 Effect of consortium member share model 6-8

So far we have estimated the effect of consortium membership on the volume of patents of the respective company. In this section, we will estimate the effect of the consortium member share (indicating how many of the firms contributing to the standard are member of the consortium) on the volume of patents filed by members and outsiders. Finally, by estimating the effect of consortium member share on patents filed by all companies, we obtain a measure of the net effect of consortia. As compared to the previous analysis, this method is less prone to endogeneity biases, as the decisions of other companies to join a consortium are probably relatively unrelated to a firm's own current or expected future R&D efforts. We are therefore less restrictive regarding the sample, and only drop observations for 2001 or earlier and of standards with no consortium within the observation period. On the other hand, the member share is sensitive to the membership decision of the firm itself, especially if the number of firms on the standard is low85. In order to check for robustness to this sensitivity, we present all results for a narrower subsample of standards including at least 6 contributing firms.

We estimate the effects of consortium member share separately for consortium members and non-members and for both. For the purpose of this analysis, a firm is labeled as a member over the whole period of observation, if it is consortium member at least once within this period. It is labeled consortium outsider if it has never been consortium member over the period of observation. We control for time-variant firm characteristics, standard-company fixed effects, the lagged dependent variable and external shocks. Results are displayed in Table 4.

[85] If we substracted the company itself from the consortium size variable, this count would be nevertheless sensitive to company membership, as we estimate the effects separately for consortium members and non-members.

	M6		M7		M8	
	Coef.	Marg. Effekt	Coef.	Marg. Effekt	Coef.	Marg. Effekt
Member_share	0.884 ***	0.884 ***	0.337	0.337	0.903 ***	0.903 ***
	(0.328)	(0.328)	(0.445)	(0.445)	(0.233)	(0.233)
Member_share *OverInvestment	-5.489 ***	-5.489 ***	-3.65	-3.65	-5.532 ***	-5.532 ***
	(1.923)	(1.923)	(2.177)	(2.177)	(1.346)	(1.346)
Lag1 Standard Activity	-0.022 **	-0.022 **	-0.035 **	-0.035 **	-0.027 ***	-0.027 ***
	(0.011)	(0.011)	(0.012)	(0.012)	(0.009)	(0.009)
Lag1 Patent Files [1]	0.013	0.013	0.078 ***	0.078 ***	0.022	0.022
	(0.018)	(0.018)	(0.028)	(0.028)	(0.021)	(0.021)
ICT Patent Files [1]	0.008 ***	0.008 ***	0.004	0.004	0.007 ***	0.007 ***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
Patent Declarations[1]	0.009 *	0.009 *	0.008	0.009	0.007	0.007
	(0.005)	(0.005)	(0.017)	(0.017)	(0.005)	(0.005)
Lag1 Sales [1]	-0.003	-0.003	0.003	0.003	-0.002	-0.002
	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Standard Year Dummies	Incl.		Incl.		Incl.	
Consortium	Member		Outsider		Both	
Log Likelihood [2]	-140.39		-29		-175	
AIC [2]	280		58		351	
BIC [2]	281		57		352	
Observations	1,288		735		2041	
Groups	169		107		276	

*Notes: All models are estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible. [2] Values are reported in thousand.*

Table 4: Results of the multivariate analysis – testing consortia member share (consortia net effect)

Consortium members react to increasing consortium member share by inflating their patent filings, but this effect decreases with the level of overinvestment (model 5). Consortium outsiders do not react in a statistically significant way to changes in consortium member share (model 6). The overall effect (the effect indistinctly for members or outsiders) of increasing consortium member share on the volume of standard-specific patents is positive and significant, but this effect decreases significantly with the level of over-investment (model 7).

3.3.5 Net effects

Our results suggest that nearly all effects of consortia depend upon the initial level of overinvestment. In order to be able to discuss the effect of consortia on patenting, one should therefore relate the estimated coefficients to the sample values of the overinvestment indicator. We calculate the net effects from the results of model 5 (for the effect of consortium membership) and model 7 (the overall effect of consortium member share in the whole sample). We find that the effect of consortia membership is positive for any share of non-practicing entities not exceeding 6 %. This is the case for 92,12% of the observations. The effect of consortia member share on overall volume of patents is positive for any share of non-practicing entities below 9 %. This is the case for 94,13% of the observations. These results indicate that the effects of consortia membership and consortia member share on standard-specific R&D are positive in a broad majority of standards[86]. However, they also suggest that consortia can have a deflating effect in a minority of standards that are characterized by a particularly strong patent race pattern.

4. Conclusion

The purpose of the paper is to assess how consortia influence the volume of patents filed around formal standards, and whether this is efficient. In the first theory section, we defined consortia as a means to reduce the degree of rivalry between the firms' innovations. Accordingly, consortium members can obtain essential patents at a lower average cost, by better targeting R&D investments. The effect on the volume of patents filed around the standard is however ambiguous. By joining a consortium, a firm may indeed file fewer patents by cutting irrelevant R&D investments or more of them if it seeks to develop more technology inputs for the standard. We have established that consortium membership is always pro-efficient if the first effect dominates. A patent-inflating consortium is also pro-efficient in a *public good* equilibrium, but it may actually harm efficiency in a patent race equilibrium if it induces an excessive inflation of patents around the standard.

Our empirical analysis makes it possible to assess which effect actually dominates, depending on the investment pattern – *public good* or *patent race* – prevailing for a given standard. When joint investments are suboptimal (*public good* pattern), the observed rise in

[86]The negative effect of consortia membership and relative consortia size on R&D investment in situations of overinvestment is however stronger than this positive effect.

patent files indicates that consortium membership induces firms to develop more innovations, rather than saving R&D costs. Since royalty-based incentives are weak in this case, this suggests that their reaction is chiefly driven by the opportunity of enhancing the value of the standard by developing more essential components. Consortia are thus an efficient way to supplement the lack of R&D investments when incentives to develop the standards are not sufficient.

Empirical results differ when the *patent race* pattern prevails. For most standards, new consortium members still increase their patent applications, but in significantly lesser proportions than in the *public good* cases. Since firms have strong strategic incentives to develop essential patents, this suggests that there are few opportunities left for developing innovations that are relevant to the standard. For some standards featuring strong overinvestment, we even observe that consortium members reduce their investments – consortia being then used to save R&D costs by eliminating irrelevant R&D investments. These results thus indicate that the creation of consortia does not significantly accentuate patent races, and rather has a pro-efficient deflating effect for at least a minority of standards around which overinvestment is particularly strong.

Chapter V : Essential Patents and Standard Dynamics

Les brevets essentiels et les dynamiques des standards

Les standards dans les nouvelles technologies de l'information et de la communication (NTIC) doivent répondre au progrès technologique tout en assurant un fondement stable pour l'investissement qui s'appuie sur le standard. Les développeurs de standards confrontés au changement technologique peuvent souvent faire le choix entre remplacer un standard existant par un nouveau standard et mettre à jour le standard existant. En étudiant le cas des organismes de standardisation formels (SDOs), nous étudions comment ce choix s'opère si le standard incorpore des composantes protégées par des brevets essentiels. Utilisant une base de données sur plus de 3.500 standards de NTIC différents, nous trouvons que les brevets essentiels réduisent la probabilité d'un remplacement du standard existant, mais augmentent le taux auquel les standards sont mis à jour. Nous argumentons que l'augmentation du nombre de mises à jour reflète une augmentation de l'investissement des firmes dans l'amélioration du standard. Cependant, le taux plus élevé de mises à jour du standard ne peut expliquer qu'en partie l'effet des brevets essentiels sur le taux de remplacement des standards. Les frictions autour d'intérêts privés entre firmes associées au développement du standard pourraient être une autre explication pour cet effet.

1. Introduction

Technological standards include an increasing number of standard-essential patented technologies (Bekkers et al., 2012). A patent is called essential if it is necessarily infringed by any implementation of the standard. Recent contributions show that the inclusion of patented technology into a standard increases the value of the patent (Rysman and Simcoe, 2008). This increased value is an incentive for companies to adjust their patent filing strategies to ongoing standardization (Berger et al., 2012), and to build up strategic alliances in order to influence the selection process in standardization (Leiponen, 2008). The positioning of the firm even has a stronger impact on the inclusion of patented technology into a standard than the technological merit of the patent itself (Bekkers et al., 2011).

While these advances have improved our understanding of the incentives and strategies of firms contributing patented technologies to a standard, we know little about the consequences of essential patents for standardization and standard users. Essential patents can discourage standard adoption, because standard adopters fear to be held up by owners of essential patents and to be faced with exorbitant requests for royalties (Lemley and Shapiro, 2006). There is also the concern that a high number of patents leads to patent thickets (Shapiro, 2001) which hamper and slow down standardization processes. Standard setting involving proprietary technologies is often subject to tensions and diverging interest between participating firms (Garud et al., 2002). Vested interests in standardization due to increasing commercial stakes reduce the speed at which new standards are developed (Simcoe, 2012). Nevertheless, it is important to also see the potential benefits of essential patents for standardization. Once their proprietary technology included, firms have a private interest in improving the standard to protect it from being replaced by rival technologies. Holders of essential patents thus become platform leaders for the standard (Cusumano and Gawer, 2002), and have an incentive to sponsor standard adoption (Katz and Shapiro, 1986) and to promote coordinated technological change (Bresnahan and Greenstein, 1999, Cusumano and Gawer, 2002). As a result, essential patents may actually accelerate the technological progress of existing standards and encourage their implementation.

It is the aim of this article to have a more comprehensive understanding of the effect of patents on the evolution of standards after their release. Standards need to respond continuously to technological innovation, as outdated standards can become an impediment to technological progress. In order to integrate new technology, standard setters can often choose between replacement and upgrade of the existing standard. While a standard upgrade only incrementally improves upon an existing standard, standard replacement indicates a more radical change in the underlying technology. On the one hand, in presence of fundamental innovation, standard replacement may be necessary in order to fully integrate the advances in the state of the art. On the other hand, standard replacement can induce loss of backward compatibility and impose higher implementation costs upon standard users compared to standard upgrades. Based upon these insights, we investigate the frequency of upgrade and replacement of standards including essential patents, as compared to other standards.

We rely upon a comprehensive database of ICT standards released from 1988 to 2008. This dataset includes detailed information for over 3,500 *de jure* standards issued by formal standardization bodies. We match the standards in our sample to a comprehensive database of patents declared to be essential and furthermore inform for each standard class the speed of technological progress, as measured by the number of patent files in the related technological field.

Essential patents tend to concentrate on highly valuable, technology-intensive standards (Rysman and Simcoe, 2008). In order to deal with this bias, we construct an appropriate control sample based upon the characteristics of the standard and the technological field. Second, we estimate the hazard rate of standard replacement over time, controlling for relevant technological events. The results show that essential patents reduce the likelihood of standard replacement, but increase the likelihood of upgrade. While standard upgrades temporarily reduce the risk of standard replacement, the effect of essential patents on standard lifetime cannot be fully explained by more frequent upgrades. This finding provides support to the hypothesis that essential patents lock in existing ICT standards and hamper discontinuous change. In contradiction with widespread concerns regarding the effect of patent thickets on standardization, the effect of including essential patents is independent of the number of patents.

Our findings have several managerial implications. For potential standard adopters, essential patents can signal that the standards will be regularly improved and are less at risk of an early replacement. Essential patents could thus reduce technological uncertainty, increase standard related investments and encourage standard adoption. This positive effect of essential patents on standard adoption could counterweigh the well-known negative effects associated with the risk of patent holdup. For patent holders, this is an argument for transparent disclosure of essential patents, weighing against the profitability of “patent ambush” strategies and other incentives for late patent disclosure (Ganglmair and Tarantino, 2012). For standardizing firms, our findings have ambiguous implications on the costs and benefits of selecting patented technology. On the one hand, inclusion of patented technology provides the standard with sponsors who have incentives to invest in standard improvements. On the other hand, the inclusion of essential patents may give rise to vested interest and compromise future changes of the standard.

2. Analytical Framework

2.1 Inertia and momentum in the innovation of network technologies

Advanced ICT technologies often build upon thousands of complementary technological ideas that are individually invented, but brought to the market in a discrete number of "generations".[87] If a new, incompatible generation is brought to the market, users must decide whether or not to incur the switching cost in order to benefit from the newer technology. The value of the new technology to the users however crucially depends upon how many other users decide to switch. Markets where adoption decisions are made independently can therefore be subject to important coordination failures, such as lock-in of outdated technologies, or stranding of adopters of a new technology that fails to attract further users (Farrell and Saloner, 1986).

Adopters of a new technology require that the technology will be kept in place for a sufficient time to justify the costs of adoption. These adoption costs are sunk, and some users will not take the risk of adopting a new technology when there is uncertainty about future technological progress (Balcer and Lippman, 1984). However, if a substantial number of users switch to the new technology, users of the old technology are stranded and suffer from loss of network effects (Farrell and Saloner, 1985). It is therefore crucial for a provider of a new network technology that he can guarantee technological stability over some time. Too frequent innovations in the network are socially detrimental. Nevertheless, network technologies also exhibit a tendency to lock-in situations and excessive inertia. Once markets widely adopt a technology; switching costs and the risks of lock-in increase (Arthur, 1989). This lock-in can be the result of the installed base of the whole technology, but also of specific network ties resulting from the adoption rate of specific components (Suarez, 2005). New technologies may thus be introduced at a too low frequency, and the users and implementers of the technology incur the opportunity cost of not using the best technology available.

[87] Generations of mobile phone standards are good examples for this process. Since the release of its first specifications in 1990, the GSM standard has continued evolving in order to integrate new functionalities, for instance related to mobile internet connection. Nevertheless, in order to obtain more significant increases especially in data transmission rates, UMTS, a new standard building upon a very different coding technology, had to be developed (Bekkers, 2001, Bekkers and Martinelli, 2012)

Lock-in of installed technologies does however not necessarily prohibit technological progress. An installed dominant design can be subject to substantial and sustained incremental progress (Abernathy and Utterback, 1978). This incremental progress follows trajectories defined by the technological paradigms of the underlying technological basis (Dosi, 1982). In contrast with these continuous technological changes along a given trajectory, a discontinuous technological change is the shifting to a superior trajectory. Christensen and Bower (1996) show that established market leaders tend to lose their leadership position when they face a discontinuous technology change. Christensen et al. (1998) provide evidence that in the case of continuous progress of a dominant design or standard, firms may retain their market positions throughout the successive technological generations. Technological incumbents thus have incentives to promote and favor continuous technological progress and to prevent discontinuous changes (West and Dedrick, 2000). The lock-in of a dominant design may however be socially detrimental, if it permanently prevents shifting to a different, more promising technological trajectory.

The socially optimal rate of discontinuous technological change strikes a balance between the discrete costs of developing and adopting new technologies on the one hand, and the continuous opportunity cost of using an outdated technology or moving along an inferior technological trajectory on the other hand. Uncoordinated deployment and adoption of new network technologies can deviate from this socially optimal rate in both directions, yielding either excessive inertia or excessive momentum (Farrell and Saloner, 1985). Liebowitz and Margolis (1995) argue that excessive inertia or momentum can be avoided if technology is proprietary. Katz and Shapiro (1986) show that the owner of a proprietary technology has an incentive to sponsor adoption costs, thereby contributing to the efficiency of standard adoption processes. Clements (2005) however finds that the incentives of an owner of a proprietary technology to have a new standard adopted deviate from what would be socially optimal and can induce excessive inertia or momentum.

2.2 Formal standardization as coordination device

Most inefficiencies in the rate of discontinuous technological change in network technologies result from the lack of coordination between the users of the technology. Often, these inefficiencies can be overcome if users can communicate and coordinate adoption decisions (Weitzel et al., 2006). In practice, coordination on adoption decisions in network technologies takes place inside more or less formal standard bodies. Participation in this collaborative standard development is a crucial factor for the success of companies in technology intensive industries (Fleming and Waguespack, 2008). Coordination on standards ensures compatibility and substantially reduces the risk for the developers and adopters of new technology (Tassey, 2000, Aggarwal et al., 2011). The different generations of technology are embedded in different generations of standards. The issuance and adoption of a new standard thus determines the common adoption of thousands of complementary technological inventions resulting in a new technological platform[88]. This process can take place more or less frequently, and the technological progress incorporated in a new standard can be more or less important.

The economic literature has addressed the issue of inertia and momentum in standard replacement mainly for the case of uncoordinated adoption decisions[89]. Timing is however a crucial problem also for formal standardization. Formal standardization results in better coordination on the best technology, but comes at the cost of decreased speed (Farrell and Saloner, 1988). Formal standard setting bodies face an important tension between responding to an advancing technological frontier and fixing a stable technological basis for creating compatible products and investing in applications and implementation (Egyedi and Hejnen 2005, Blind and Egyedi, 2008). Technological change exerts a constant pressure on standard setting bodies to revise existing standards. Consistently, an empirical analysis of factors influencing the lifetime of national ICT standards (Blind, 2007) has revealed that standard survival time decreases with the speed of innovation, as measured by patent files in ICT in the respective country.

While standard bodies coordinate on adoption decisions, both advances in the technological frontier resulting in opportunities for new standard generations and the development of improvements and implementations of existing standards are subject to independent investment decisions. Coordinated adoption decisions may be insufficient to prevent excessive inertia or excessive momentum, if there is no coordination on the complementary investment. Investment in R&D for new standards or applications of existing standards is subject to competition, complex strategic alliances (Leiponen, 2008) and potential coordination failures (see Chapter 4). The incentives of firms to invest in R&D and to develop applications are shaped by the extent to which technology holders can use patents to appropriate important parts of the value generated by the standard.

[88] For recent case studies of the interplay between standardization and innovation, see Bekkers and Martinelli (2012) and Fontana et al. (2009).
[89] Farrell and Saloner (1985, 1986), Katz and Shapiro, (1992), De Bijl and Goyal (1995), Kristiansen (1998)

2.3 The role of essential patents

Essential patents play an important role in standardization, as they provide incentives for firms to develop technologies for standards and to contribute to the effort of standardization. Standardization entails a costly private investment into a public good (Kindleberger, 1983). Due to this externality, standard makers underinvest in developing and improving standards. The prospect to include their proprietary technology into technological standards is an important incentive for firms to increase their investment in standardization (Rysman and Simcoe, 2008). Patent holders also have a stronger private interest to invest in improvements of existing standards if they can recoup the costs through licensing fees. Standards are a good illustration of the argument raised by Kitch (1977) that Intellectual Property Rights are important for innovation not only as a reward for successful innovators, but also to ensure incentives in continuous investment in improving the protected technology. Empirical findings show that patents reduce uncertainty to incur investments that are complementary to a specific technological choice (McGrath and Nerkar, 2004, Arora et al 2008). However, there is so far no evidence for such effects of patents that are essential to standards. The incentive for owners of essential patents to regularly upgrade a standard is expected to be particularly strong when the technological evolution in the sector generates pressure for standard replacement. Holders of essential patents have an incentive to develop and advocate continuous marginal improvements that avoid challenges from incompatible rivaling technologies. West and Dedrick (2000) and Dedrick (2003) show that IPRs are an important tool for allowing the owner of a platform to control a coherent evolution of the platform architecture. If the inclusion of essential patents signals that the standard will be regularly improved, but faces less risk of replacement, essential patents could also be a valuable commitment device that encourages standard implementation and reduces welfare losses from under-investment in standard adoption.

In spite of these virtues, essential patents have also drawbacks for standardization. For instance, patents on formal standards can generate conflicts among standard makers regarding the shares of proprietary technology covered by the standard. Evidence for this concern can for instance be found in the survey which is part of the "EU Study on The Interplay of IPR and Standards". Surveyed practitioners see consensus reaching and the speed of standardization processes to be the most negatively affected fields when essential IPRs are introduced to a standard (Blind et al., 2011). Essential patents can lead to a time-consuming « war of attrition » in building consensus on a new standard (Farrell and Simcoe, 2012; Simcoe 2012). Practitioners report cases in which holders of patented technology "*would only agree to a certain standard if they are allowed to integrate their technology, which makes the standardization process more complex and time-consuming and sometimes* *even induces errors on products*"[90]. Conflicts between holders of technology are even more likely to delay standard replacement than the development of a completely new standard. As formal standard development is, at least in principle, a consensus decision, owners of components of the existing standard can oppose to any standard replacement unless they are fully compensated by sponsors of the new standard.

If holders of standard essential technology exercise a high degree of control over a standard, they may on purpose "kill off" the incumbent technology by introducing new versions which are not backward compatible (Iizuka, 2007). For the case of network externalities Waldman (1993) and Choi (1994) show that firms' incentives to introduce incompatible new products are too high compared to what is socially optimal. These strategies of planned obsolescence are especially beneficial in monopoly situations such as the case of holders of essential patents (Choi, 1994). However, in the case of formal standardization, the rules of standard setting organizations require consensus decision making. While consensus decision making allows single players to oppose to changes and thus to delay or prevent releases of new standards, even dominant firms would not have the means to enforce planned obsolescence against the interests of other participants.

From the academic literature and practitioner statements, we thus draw the following hypotheses: first, essential patents allow some degree of internalization of the costs of standard improvements and therefore provide incentives for patent holders to invest in standard upgrades. These incentives are particularly strong if investing in standard upgrades is a way of reducing the risk of obsolescence and replacement by a different standard.

Hypothesis 1: The inclusion of essential patents induces incentives to invest in continuous technological progress, which results in more frequent standard upgrades.

Second, the continuous upgrade of standards delays standard obsolescence. Furthermore, holders of essential patents have an incentive to oppose standard replacement and exclusion of their proprietary technological components from the standard. Both factors concur, and essential patents are expected to delay standard replacement.

Hypothesis 2: The inclusion of essential patents increases the persistence of existing standards and reduces the risk of standard replacement and discontinuous technological

[90] The interview with Dr. Ivstan Sebestyen held in April 13th 2010 was conducted in the context of a fact finding."EU study on the Interplay of IPR and Standards". Ivstan Sebestyen has been involved in the worldwide multimedia standardization work for over 20 years including telecommunication standardization experience in CCITT, ITU-T, ISO/IEC, ETSI and DIN and ITU-T and still picture coding (JPEG, JBIG).

change. We will test these hypotheses empirically using comparative and econometric analysis.

3. Empirical Methodology

3.1 Identifying standard upgrades and replacements

We analyze the rate of standard upgrade and replacement using a comprehensive database of international ICT standards drawn from PERINORM. PERINORM is the world's biggest standard database with bibliographic information on formal standards and is regularly updated by the SDOs DIN, BSI and AFNOR. We include all ICT standards (ICS classes 33 and 35) issued by the main formal international SDOs (ITU-R, ITU-T, IEEE, ISO, IEC, JTC1). We restrict the analysis to *de jure* standards issued from 1988 to 2008, and we observe these standards until 2010. We start in 1988, because the *International Telecommunication Regulations* issued in 1988 constitute an important policy change, leading to changes in the way standards are released. Draft standards, amendments and errata documents as well as technical reports and other documents produced by SDOs that are not standards are screened out using the document codes in the name of the document. This yields a sample of 7,625 standards. For the econometric analysis, we furthermore restrict the sample to technological fields where there is a potential for essential patents (fields in which at least one standard includes essential patents) and exclude standards with missing explanatory variables. This sample comprises 3,551 standards, 4,671 standard versions and 36,179 standard-year observations. 367 standards and 1,709 standard versions included in this sample have been withdrawn during the observation period.

For every standard version, the database gives precise dates of release and withdrawal. SDOs regularly revise their standards to keep up with technological progress. During the revision, „*a majority of the members of the TC* (Technical Committee) *decides whether the standard should be confirmed, revised or withdrawn*"[91]. We can observe withdrawal of standard versions in PERINORM, and identify new versions of the same standard using PERINORM information on standard history. To give an example, the MPEG2 Video standard version ISO/IEC 13818.2(1996) was withdrawn in 2000 and replaced by ISO/IEC 13818.2(2000)[92]. This new version consolidates several corrigenda and amendments made to the standard since the release of the first version in 1996. New encoders or decoders

[91] http://www.iso.org/iso/standards_development/processes_and_procedures/stages_description.htm
[92] MPEG2 is a widely used coding technology for video and audio content. For an overview of the second edition, see http://webstore.iec.ch/preview/info_isoiec13818-2%7Bed2.0%7Den.pdf

produced according to the new standard are fully compatible with media or devices produced according to the previous version. We consider that in such a case where a standard version is replaced by a more recent version, the standard is revised and simply upgraded. These upgrades reflect continuous technological change along the technological trajectory defined by the standard and the embodied technological basis.

If a standard version is withdrawn without a direct successor, we consider that the standard is replaced. In practice a standard is generally not withdrawn immediately when a new generation of standards is released. For example, several generations of mobile phone standards (GSM and UMTS) and audio and video coding standards (MPEG2 and MPEG4) currently coexist. Nevertheless, evolution and deployment of new generations eventually lead to the earlier standard being withdrawn. The SDOs point to technological progress of as a main reason for withdrawing standards: "*Several factors combine to render a standard out of date: technological evolution, new methods and materials, new quality and safety requirements*[93]*".* Earlier research (Blind, 2007) and our own empirical analysis confirm the direct link between standard withdrawal and related technological innovation. We therefore use the withdrawal of a standard version without direct successor to indicate standard replacement, a discontinuous technical change that renders the standard obsolete.

We can thus differentiate between standard upgrade and standard replacement and calculate the survival rate of standards and standard versions. The survival time of standard versions is hereby defined as the time from version release to version withdrawal, and the survival time of standards is the time elapsed between release of the first standard version and standard replacement. We investigate the effects of our explanatory variables on these rates using duration analysis.

In the case of our example, the standard ISO/IEC 13818.2 is part of a group of standards that are closely related. Indeed, this standard defines the video coding technology of MPEG2, which also includes other components dealing e.g. with audio coding. These connections between standards lead us to worry that the survival rates of the different observations in the sample are not determined independently, and that failure to account for this could overstate the significance of the results. In order to account for this, we define clusters of standards that can be identified as belonging to a common family of standards[94].

---

[93] http://www.iso.org/iso/standards_development/processes_and_procedures/how_are_standards_developed.

[94] We identify clusters using the number until the dots in the case of ISO, IEC, and JTC1, until the slash for ITU-T and ITU-R, and using only the numbers and not the letters in case of IEEE (e.g. IEEE802.11n is identified as belonging to IEEE802.11)

3.2 Explanatory variables

We match the standards in our sample to a database of declared essential patents. Declarations of essential patents have been downloaded from the websites of the SDOs in March 2010. The declaration of patent essentiality is made by holders of the patents, and no external validation of this essentiality claims is made. There is furthermore no guarantee that all essential patents are accurately declared. The existing literature has nevertheless found that declared essential patents are a reasonable proxy for essential patents, and that the date of declaration proxies the date of inclusion into a standard (Rysman and Simcoe, 2008). In the following we will speak of essential patents, empirically approximated by our database of patent declarations. We identified more than 8,000 patent declarations for 700 formal standards included in our sample. In order to analyze the effect of essential patents on the rates of standard upgrades and replacements, we can then compare the respective survival rates of standards and standard versions including essential patents with standards in the remainder of the sample. This comparison is however subject to several potential biases. Essential patents could indicate that a standard has a stronger focus on innovative technology, and is thus subject to faster changes in the state of the art. On the other hand, patent holders may prefer declaring essential patents on standards with a long expected lifetime. Finally, declarations of essential patents could also signal the importance, technological complexity or commercial relevance of a technological standard. All these factors are likely to have an impact upon the survival rate of standards and standard versions.

We therefore make use of a broad range of technological indicators including the issuing SDO, the ICS (International Classification of Standards), the breadth of the technological scope (approximated through the number of ICS classifications, which we will refer to as "*ICS width*"), the number of pages, standard modifications, and references to prior standards (*backward references*). We also count accreditations of the standard that have taken place before the standard release at the body in our sample (*prior accreditations*). This happens when the standard has not been first issued by one of the SDOs we observe (for example if a national standard is accredited on international level). These standard characteristics are time-invariant, and are therefore particularly suitable for the construction of a control group of standards whose evolution over time can be compared with standards including essential patents.

However, this sampling approach is not effective to control for time-variant factors and to analyze the interplay between essential patents and standardization dynamics. In a second step we will therefore propose a multivariate panel analysis, where explanatory variables are allowed to vary over time. In the majority of cases, the patent declaration database informs the date of declaration, so that we can match each of these essential patents to its relevant standard at any time from the year of declaration.

We approximate the evolution of the state of the art using information drawn from essential patents. Building upon Chapters 3 and 4, we use the technological classification of declared essential patents to match patent and standard classes in the field of ICT. We can thus identify how many patents are filed in fields that are potentially relevant for the standards in the different ICS classes. Thus we can inform for each standard class on a relatively disaggregate level the speed at which the state of the art evolves (in the following, we refer to this variable as "*innovation intensity*"). Blind (2007) has shown that the replacement rate of national ICT standards increases with the number of ICT patent files in the respective country. In our data, we can identify innovation rates that are more closely related to specific standards. The yearly patent files in the related field indicate the flow of standard-related inventions. Following Hall et al. (2000) and Bessen (2009)[95], we accumulate these yearly flow data to a standard-related knowledge stock which depreciates at 15% per year. This knowledge stock approximates the "*technology gap*" or distance of the standard to the technological frontier. We assume that a new standard release fully integrates the advances in the state of the art, so that the technology gap is set back to zero.

It is also important to control for standardization activities related to the standard that are likely to have an impact on the probability of standard replacement. We build a variable indicating changes to referenced standards upon which the standard is built (*change of referenced standard*). Changes upstream in the technological architecture are a decisive factor of changes of depending downstream standards. For the same reason, we include references from other standards (*forward references*) and accreditations by other SDOs (*ulterior accreditations*). As these downstream standards need to be replaced when the standard itself is replaced, forward references and accreditations increase the social cost of standard replacement. These variables are likely to capture up to some extent downstream investment building upon the standard.

A full list of variable definitions is provided in Appendix 1.

[95] Park and Park (2006) provide a list of industries and estimate the depreciation rate of related patents. ICT standards of our sample can be categorized to the industry code 17: Electrical machinery and apparatus n.e.c. (ca. 14%) as well as the industry code 18: Radio, TV and communication equipment and apparatus (ca. 16%).

3.3 Sampling

It is the objective of our analysis to compare standards including essential patents with other standards. However, essential patents are not randomly distributed over the standards in ICT. Many of the factors affecting the likelihood of including essential patents are also likely to have an impact on the duration until standard upgrade and replacement.

We therefore build an appropriate control group in order to be able to present meaningful descriptive statistics. First, we eliminate standards issued before 1988. We then carry through a propensity score matching based upon a broad range of observable fixed standard characteristics. The determinants of the inclusion of essential patents can be classified into three groups: first, several technological variables can be used as indicators of complexity or value. For instance, the number of standard pages is an indicator of the size of the standard, and the technological complexity of the issues that it addresses. Being referenced by other standards in the first years of standard life is an indicator of the relevance of the standard for further technological applications. We use a reference window of four years, by analogy to the common practice of citation windows as indicators of patent significance (Trajtenberg, 1990). Second, technological classes of standards capture whether a standard is in an innovative and patent-intensive field, or rather in less innovative fields, where essential patents are less likely to occur. Third, the issuing SDO has a statistically significant impact upon the likelihood that the standard includes essential patents. This could be due to more or less stringent rules regarding the declaration of IPR, but it could also reflect the fact that standardizing firms target patent-friendlier standard bodies as a forum for a standards project when they own proprietary technology that they wish to have included (Chiao et al., 2007). Appendix 1 presents the results of the regressions through which the propensity scores were calculated, and depicts the repartition of the propensity scores over standards including essential patents and other standards.

Building upon this propensity analysis, we eliminate the observations that have a lower propensity score than the treated observation (standard including essential patents) with the lowest propensity score. We then group the remaining observations into six strata of equal size[96]. Appendix 1 provides details of the calculation of propensity scores and gives an overview how standards are distributed over the different strata. The propensity scores increase with ascending strata numbers. The share of standards including patents increases

[96] According to Caliendo and Kopeinig (2008), five strata are often enough to remove the bias from the data. As our propensity score is very skewed, five strata are not enough to equalize all important variables among control and treated within the strata, but more than six strata would leave us with very small numbers of treated standards in the lower strata

from strata to strata, reflecting that the model is somehow successful in identifying the factors explaining inclusion of essential patents.

4. Comparative Analysis

4.1 Descriptive Survival Analysis

In this section, we will present results of a comparative statistical analysis. We first compare the survival rates of standard versions including essential patents with other standard versions. Figure 1a shows the Kaplan-Meier estimates of the likelihood that a standard version has not been withdrawn by a certain time (indicated in years after release). Survival rates of standard versions including essential patents decrease more rapidly than those of other standard versions (Figure 1a). This figure does however not indicate whether the observed difference is a causal effect of essential patents, or whether essential patents are more likely to be declared for standard versions that would have had lower survival rates anyway. For instance, we could expect that patents are more likely to be declared on more important standards or on standards that are more responsive to technological change. Figure 1b corroborates this concern. Comparing the survival estimates of the different strata (strata 1 with the lowest likelihood of essential patents, strata 6 with the highest), we observe that standards a priori most likely to include essential patents are upgraded more often.

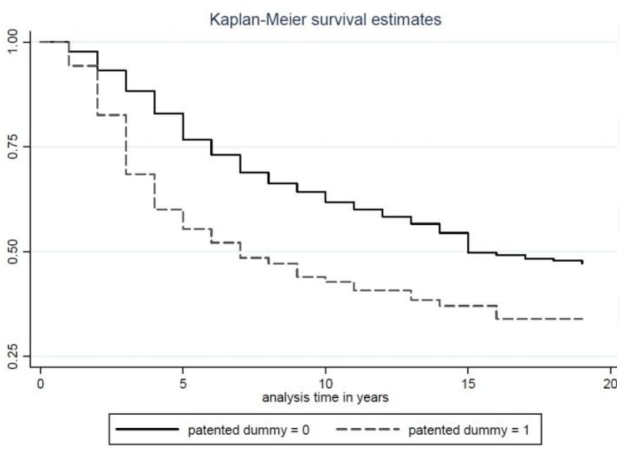

Figure 1a: Survival estimates of standard versions, including and not including patents

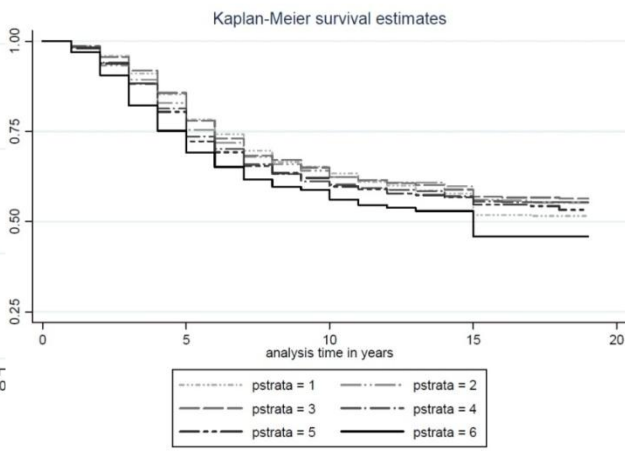

Figure 1b: Survival estimates of standard versions, by strata

In order to control for this selection effect, we have to make the comparisons within the strata. Table 1 displays results of a log-rank test of equality of survivor functions of standard versions. We observe the withdrawal of 391 standard versions including essential patents. If essential patents had no effect on standard version survival, we would expect only 225 versions to be withdrawn during the observation period. Carrying through the analysis by strata of propensity scores even exacerbates the difference between the observed and expected standard version survival rates[97]. Significant differences are observed within all the strata, except for strata 1 and 2, where numbers of standards including essential patents are very low.

Version Upgrade		Stratified by SDO and ICS	Stratified by 6 PSM strata	Within Strata 1	Within Strata 2	Within Strata 3	Within Strata 4	Within Strata 5	Within Strata 6
	Events								
Patented	Obs: *Exp:*	391 *225.50*	350 *192.20*	3 *3.20*	14 *9.55*	47 *17.16*	57 *21.25*	79 *39.07*	150 *101,98*
Non-patented	Obs: *Exp:*	5147 *5312.50*	2131 *2288.80*	421 *420.80*	473 *477.45*	392 *421.84*	349 *384.75*	250 *289.93*	246 *294,02*
Chi2 Pr>chi2		140,75 0,0000	167.29 0.0000	0.01 0.9076	2.29 0.1304	58.30 0.0000	67.73 0.0000	48.91 0.0000	32.70 0.0000

Table 1: Log-rank tests of equality of version survival functions
Standards including and not including patents, by strata, within strata

We have discussed that standard versions can be withdrawn in cases of either standard upgrade or standard replacement. We will therefore compare the survival rates of standards. The survival time of a standard is defined as the time elapsed between release of the first version and withdrawal of the last version of the standard (standard replacement). We can see on Figure 2a that the survival estimates of standards including patents decrease slower than what can be observed for other standards. On figure 2b, we see the survival estimates by strata. Standards that are – based upon their observable characteristics – least likely to include essential patents (Strata 1 and 2) have significantly lower survival estimates. Patents are thus more likely to be declared on standards with a longer expected lifetime.

[97] Some observations are excluded because of missing values. Notice also that we excluded all standards with a propensity score that was lower than the lowest score of a standard including patents.

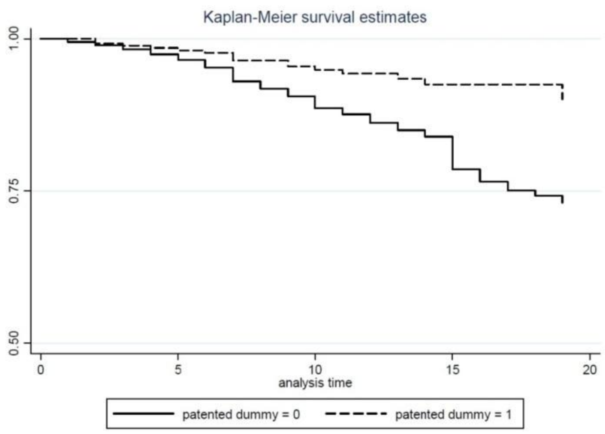

Figure 2a: Survival estimates of standards, including and not including patents

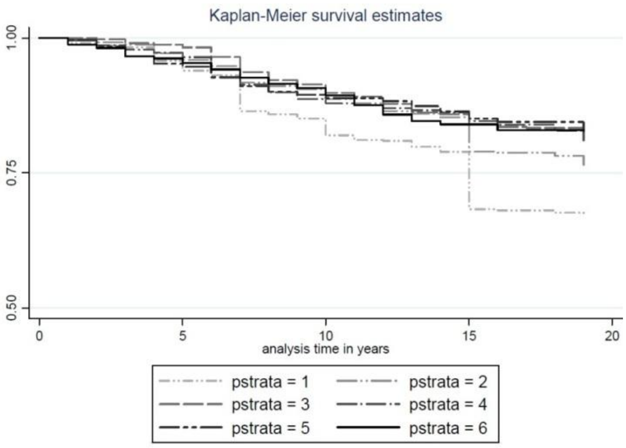

Figure 2b: Survival estimates of standards, by strata

To account for this selection effect, we once again carry through the comparison by strata. We observe 22 replacements of standards including essential patents. Had these standards the same survival functions as other standards, we would expect 67 standard replacements. If we carry out the comparisons by strata, we remove the selection bias based upon observables. The number of expected replacements decreases to 42, which is still much higher than the observed 21. There is thus strong evidence for inequality of survivor functions. Differences are statistically significant within strata 5 or 6. The numbers of standards including patents are probably too small in the other strata to yield reliable results.

Standard Replacement		Stratified by SDO and ICS	Stratified by 6 PSM strata	Within Strata 1	Within Strata 2	Within Strata 3	Within Strata 4	Within Strata 5	Within Strata 6
	Events								
Patented	Obs: *Exp:*	22 *66.92*	21 *41.89*	2 *1.17*	0 *2.61*	2 *3.25*	5 *4.73*	3 *9.93*	9 *20.21*
Non-patented	Obs: *Exp:*	1864 *1819.08*	714 *693.11*	201 *201.83*	150 *147.39*	108 *106.75*	99 *99.27*	85 *78.07*	71 *59,79*
Chi2 Pr>chi2		32.87 0.0000	12.41 0.0004	0.61 0.4349	2.67 0.1021	0.49 0.4818	0.02 0.8985	5.48 0.0193	8.34 0.0039

Table 1: Log-rank tests of equality of standard survival functions
Standards including and not including patents, by strata, within strata

The comparative analysis thus indicates that standard versions including essential patents have a shorter expected lifetime, while standards including essential patents have a longer expected lifetime than comparable standards. These findings are consistent with our two hypotheses: essential patents induce more frequent standard upgrades, while reducing the likelihood of standard replacement.

Standards including essential patents have significantly higher survival rates in all SDOs except IEC. The number of IEC standards including essential patents is very low, and only two IEC standards including essential patents have been withdrawn in the observation period. Also the difference regarding standard versions does not seem to depend upon the identity of the issuing SDO. The survival rate of standard versions including essential patents is significantly lower for all standard bodies with a large number of standards including essential patents. There are no significant differences only in the groups of standards issued by ITU-R and ISO.

4.2 Robustness analysis

The stratified analysis removes the bias based upon observable standard characteristics. We might worry that the remaining, unobservable explanatory factors of patent declaration could also have an influence on standard upgrades and replacements. Our matching of standards based upon the technological class or the issuing SDO, while ruling out that these observable factors affect the comparability of standards, could actually have increased the difference between standards in terms of unobservable characteristics. If standards in patent-intensive technologies and issued by patent-friendly SDOs nevertheless do not include any essential patents, they are likely to be different in some other, unobservable respect from standards actually including patents. For instance, we risk comparing important standards with less important standards. If our control variables are unable to control for these factors, it might be preferable to compare standards including essential patents with other standards that do not include essential patents because of observable characteristics, such as the technological field or the issuing SDO.

Based upon this reasoning, we can construct three different control groups. The first group includes the standards in the same technological field (ICS) as standards including essential patents (list in Appendix 2), but issued by SDOs having few declarations of patents (ITU-R, ISO and IEC, see Appendix 2). The second group includes standards in ICS with few patents, but issued by SDOs issuing many standards including patents (ITU-T, JTC1 and IEEE). The third group consists of standards in patent-intensive ICS issued by SDOs with many essential patents. The latter group is over-represented in the upper strata of the comparative analysis, but might be a bad control group based upon unobservable standard importance or commercial relevance. No control group is perfect. But each control group is different from the standards including essential patents for a different reason, and having several control groups allows us analyzing whether our control variables account for the unobserved biases (Rosenbaum, 1987).

Comparing survival estimates between the group of standards including patents and the three control groups, we find very significant differences not only between our standards of interest and the controls, but also among control groups. If however we stratify by the technological indicators used in the propensity score estimation (including the share of IT and Telecom standards and the years of standard release) statistically significant differences among control groups disappear (see Appendix 2). This indicates that these variables can account for the relevant bias in the data (Rosenbaum, 1987). Even accounting for the technological characteristics of standards, differences between standards including essential patents and the controls remain strongly significant[98].

5. Multivariate Panel Analysis

5.1 Estimation

The comparative analysis has revealed that standards including essential patents are less likely to be replaced, but more frequently upgraded. We will next proceed to an econometric analysis. This research framework allows us analyzing the effects of essential patents on standard upgrades and standard replacement, as well as the interactions between the rates of standard upgrades and standard replacements. First, on the version level, we estimate the risk of the version to be withdrawn (model 1). Analysis time in this setting is time elapsed since version release, and the estimated failure of the observation is withdrawal of the standard version. The withdrawal of a standard version can be explained either by standard upgrade or standard replacement. We can then differentiate between the effects of essential patents on the competing risks of standard upgrade and standard replacement (model 2). The two events exclude each other, and we speak of competing risks. SDOs face a choice between upgrade and replacement. We will analyze separately this choice using a logit

[98] Applying the analysis to standard upgrade, we find that the bias is X-adjustable between the samples of standards issued by the same SDOs (in patent-intensive or other technological fields). Other SDOs upgrade their standards less often, even accounting for technological characteristics. This leaves us with two valid control groups, displaying very significant differences with the standards including patents (Appendix 3, Table 13).

model (model 3): conditional upon a version being replaced, we analyze how essential patents affect the likelihood of standard replacement rather than upgrade.

The effects of patents on standard replacement can then be studied on the standard level (model 4). In contrast to the previous analysis, the unit of observation is the standard, and observation time is from the release of the first until withdrawal of the last version. In model 5, we take into account releases of the different versions as events affecting the survival rate of the standard. It is possible to analyze the risk of standard replacement using two different ways of controlling for upgrades: first, we introduce a variable counting the number of upgrades. Second, we include a variable indicating the time elapsed since the last upgrade. As the time elapsed since first release of the standard is used for the baseline hazard, this version age variable indicates the effect of failure to upgrade on the risk of standard replacement. The comparison between Models 4 and 5 allows estimating whether controlling for upgrades captures the effect of essential patents on standard replacement.

The effect of the variables is tested using a Cox model, a semi-parametric survival analysis. In the Cox model, the likelihood of withdrawal (hazard) is estimated year by year, conditional upon the fact that the version or standard has not already been withdrawn. The estimated hazard is a multiplicative of a baseline hazard $h_0(t)$, varying over time, and the covariates multiplied by constant coefficients:

$$h\ (t|x_{j,t}) = h_0(t) \times \exp\ (x_{j,t}\beta_x)$$

$h_0(t)$ and covariates $x_{j,t}$ are allowed to vary over time, but estimated coefficients β_x are constant over the time of observation. The Cox model therefore rests upon the Proportional Hazard (ph) assumption that the real effect of the covariates is independent of the observation time. We are unwilling to make this assumption for several factors expected to have important and not necessarily linear effects on the timing of standard withdrawal. This is the case for the issuing SDO, the technological field, and the period of standard release. In order to control for these factors, we use stratified survival analysis. In stratified survival analysis, the observed individuals *j* are classified into strata *j*. The baseline hazard rate is allowed to vary between the strata, but the effect of the explanatory variables is jointly estimated in all strata. We stratify jointly by SDO, ICS class and cohorts of standards released before and after 2001.

$$h\ (t, i, x_{j,t}) = h_0(t|i) \times \exp\ (x_{j,t}\beta_x)$$

The remainder of the variables is included as covariates $x_{j,t}$ in the Cox model. We test for the functional form of the variables using the residuals of a stratified null model. It results that the count of forward and backward references has non-linear effects on withdrawal rates, and we transform these variables in log. For the remaining variables, we see no indication of non-linear effects. We then estimate Cox models including all variables and interaction terms between variables and observation time. Insignificant interaction terms and variables are progressively dropped. Finally we test the ph hypothesis for all the chosen models. Even including interaction terms, these tests reject the ph hypothesis unless we further stratify the sample. We therefore stratify standards by ranges of standard size (number of pages), and standard versions by their position in the series of successive versions (e.g. first version, second version, and so on).

The effect of patents can be estimated in various ways. First, we test for the effect of including essential patents or not. This is done via a dummy variable which is one if at least one essential patent has been declared ("Patented"). Second, we count the number of patents declared over time, and include this count as a second explanatory variable ("Patents_cumulative"). The results are presented in Table 3[99]. We report hazard rates, which can be obtained from the estimated coefficients as $hr_1 = \exp(\beta_1)$. The hazard rate of *patented* can then be interpreted as the factor by which the hazard of version withdraw or replacement is multiplied if a standard includes essential patents, all other variables being held constant:

$$hr_{patented} = \frac{h_0(t|i) \times \exp(x_{j,t}\beta_x + \beta_{patented})}{h_0(t|i) \times \exp(x_{j,t}\beta_x)}$$

	Version survival		Replace-ment vs Upgrade	Standard survival	
	Model 1	Model 2	Model 3	Model 4	Model 5
Variable name	Cox Regression	Competing risk Cox	Logit	Cox regression	Cox regression
Patented	1.41036*** z: 3.62		-1.26969*** z: -2.61	0.39669** z: -2.22	0.43528** z: -1.99
Patented* Upgrade		3.70638*** z: 6.60			
Patented*Re-Placement		0.02290*** z:-5.85			
Patented* Upgrade_age		0.92696* z: -1.85			
Patented*Re-placement_age		1.34151*** z: 3.69			
Patents cumulative	1.00207 z: 1.33	1.00214 z: 1.34	-0.02486 z:-0.73	0.98842 z: -0.70	0.98697 z: -0.78

[99] The number of subjects at risk reported by the competing risk model is twice the number of standard versions, as each version faces two different risks. In the logit model, SDO and technology fixed effects are controlled for using dummy variables (coefficients not reported)

Technology gap	0.48055* z: -1.83	0.52004* z: -1.67	-0.12399 z: -0.68	0.89398 z: -0.51	0.63356 z: -0.98
Technology gap_age	1.10171* z: 1.84	1.09155* z: 1.69		1.04837** z: 2.03	1.00752 z: 0.14
Innovation Intensity	3.03448 z: 1.33	2.87475 z: 1.28	1.34117* z: 1.82	0.16776 z:-1.50	0.41715 z: -0.65
Innovation Intensity_age	0.98418 z: -0.12	0.99139 z: -0.07		1.6914*** z: 3.10	1.81033*** z: 3.21
log(Backward references)	0.90803*** z: -3.08	0.90924*** z: -3.00	-0.04919 z: -0.62	0.85831* z:-1.89	0.86837* z:-1.76
Change of refe-renced standard	1.01430 z: 0.27	1.01369 z: 0.26	0.20009*** z: 3.26	1.5832*** z: 7.45	1.61017*** z: 8.00
Change of referenced standard_age	1.06194*** z: 4.88	1.06241*** z: 5.01			
log(Forward references)	1.06194*** z: 5.31	1.21710*** z: 5.50	-0.50629*** z:-5.46	0.79521** z:-2.20	0.77905** -2.29
Ulterior accreditations			0.13872 z: 1.54	1.1858*** z: 3.14	1.16642*** z: 3.14
accreditations_ age			-0.02306** z: -2.44	0.9771*** z:-2.92	0.98025** -2.38
Number of pages			-0.00163** z:-1.99		
ICS width			0. 89885* z: 1.85		
Year	0.96885*** z: -2.99	0.96985*** z: -2.93	-0.00743 z: -0.32	1.04108 z: 1.31	1.04724 z: 1.53
Version Age			0.18618** z: 2.01		2.44156*** z: 4.29
Version Age_Sq					0.97290*** -2.85
Version number			-0.02016 z: -0.18		6.64184** 2.38
Version number_Sq					0.71194** -2.01
Subjects	4671	9342	Cons: 10.064	3551	3551
Failures	1709	1709	Obs: 1399	367	367
chi2	217.91	372.84	267.00	119.28	155.61
Log-likelihood	-5343.9173	-6422.0711	R2:0.3152	- 1014.5515	-1005.7632
Proportional Hazard test	Chi2: 16.35 Pr:0.1285	Chi2: 13.76 Pr:0.4681		Chi2: 12.92 Pr:0.3751	Chi2: 19.20 Pr:0.2585

Table 3: Results of the multivariate panel analysis. Results of Models 1,2, 4 and 5 display hazard rates. Models 1 and 2 are stratified by SDO, ICS, cohort and version number, Models 4 and 5 by SDO, ICS, cohort and standard size range.

5.2 Results

The econometric results confirm our hypotheses and descriptive findings. First, we confirm Hypothesis 1: the inclusion of essential patents reduces the survival rate of standard versions, meaning that standards with patents are upgraded more frequently (model 1). This effect is significant and sizeable: the inclusion of essential patents increases the rate at which standard versions are replaced by more than 40%. We then analyze the survival rate of standard versions distinguishing between the two competing risks of standard upgrade and replacement. We find that essential patents have very different effects on the two different risks: the inclusion of essential patents strongly increases the likelihood of upgrade, but strongly reduces the risk of standard replacement (model 2). Both of these effects however decrease with the age of the standard version. We then directly model the choice between upgrade and replacement (model 3). Conditional upon a standard version being withdrawn, the inclusion of essential patents significantly increases the likelihood of the version being replaced by a new version of the same standard.

Essential patents lead to withdrawing standard versions more often, but also increasing the likelihood of choosing standard upgrade rather than replacement. The resulting net effect on the survival rate of standards is unclear. We therefore estimate the effect of essential patents on the hazard of standard replacement and confirm Hypothesis 2: Essential patents reduce the likelihood of standard replacement (model 4). This effect as well is significant and sizeable: holding constant other variables, the inclusion of essential patents reduces the rate of standard replacement by 60 %. As discussed, one potential explanation for this finding is that more frequent upgrades delay the obsolescence of standards and therefore reduce the risk of standard replacement. Models 1 and 2 have confirmed that the inclusion of essential patents increases the rate of standard upgrades. Model 5 furthermore confirms that a standard upgrade temporarily reduces the risk of standard replacement. This can be seen from the fact that the risk of standard replacement increases with version age[100], while controlling for the baseline age effect. However, controlling for standard upgrades only slightly reduces the magnitude and significance of the effect of essential patents on standard replacement (model 5).

[100] The effect of version age is non linear, but the risk of standard replacement strictly increases with version age over the first 16 years of the version lifetime. The longest observed version lifetime in the sample is 19 years.

5.3 Discussion

The results show that essential patents increase the rate of standard upgrades, but reduce the rate of standard replacement. The inclusion of patented technology into a standard provides the holder of essential patents with incentives to regularly invest in further improvements of the standard. Arguably, one main incentive for the holder of essential patents to invest in improving the standard is to prevent standard replacement by keeping the standard up to date. However, this mechanism only accounts for a small part of the observable effect of essential patents on the rate of standard replacement.

These findings indicate that essential patents contribute to reduce the rate of standard replacement also through other mechanisms. Earlier findings (Simcoe, 2012) show that higher commercial stakes in standardization slow down the development of new standards. This effect is arguably much stronger for the replacement of existing standards. We argue that essential patents on a standard raise the standardizing firms' resistance to radical changes of the standard excluding patented technological components. This argument corroborates suspicions that essential patents increase inertia of technological standards. In contradiction with widespread concerns about the negative effects of patent thickets, we do however not find any evidence that the evolution of standards is affected by the number of essential patents. Indeed, the only significant effect is the difference between standards including at least one patent, and those not including any essential patents.

There are also other, complementary explanations for the effects of essential patents on the rate of standard replacement. As has been argued by Liebowitz and Margolis (1995) and Katz and Shapiro (1986), holders of proprietary standard components have an incentive to sponsor standard adoption and complementary investments. If the installed base of a standard and the value of complementary assets increase, the social costs of switching to a new standard also increase. We do not directly observe standard adoption. However, we have proxies for technological investment building upon the standard. If the technology building upon a standard is standardized itself, the more recent standard references the standard it builds upon. Using forward references as a proxy, we find that downstream investment building upon a standard reduces the risk of standard replacement. For instance references by ulterior standards strongly increase the likelihood of choosing standard upgrade rather than standard replacement. This finding corroborates our hypothesis that standard upgrades generate less problems of backward compatibility. If the number of applications building upon a standard increases, the cost of backward incompatibility increases, making standard replacement increasingly unattractive.

The analysis of the other control variables reveals that our model is able to capture key aspects of our analytical framework. We already confirmed in the comparative analysis that our control variables capture a significant part of the heterogeneity between standards. The panel analysis now also reveals that our variables capture well the time-varying effects on standard evolution. The likelihood of standard replacement is strongly associated with the "*technology gap*", the weighted stock of patents filed in the broader field over the years since the last standard release. The technological gap has no effect on very early standard replacement, but its effect strongly increases over standard age, and the average sample effect is positive and significant. This indicates that standard replacement indeed responds to progress in the field of science and technology. We also find that strong related technological progress ("*innovation intensity*") induces standardizing bodies to choose standard replacement rather than upgrade. This finding could indicate that standard upgrades are a less effective means of catching up with the technological frontier. The latter argument is important, as we have seen that essential patents induce a substitution of standard upgrades for standard replacement.

We also find strong evidence for significant interdependence of standards. Backward references to other standards strongly reduce the risk of standard replacement. This indicates that a standard building upon a more comprehensive architecture of other standards is less at risk of being replaced. If a referenced standard is replaced or upgraded ("*Change of referenced standard*"), there is however a very strong pressure to upgrade or replace the referencing standard as well.

6. Conclusion

We have presented empirical evidence that essential patents reduce the likelihood of standard replacement. This finding could indicate that essential patents lead to frictions in standardization, for instance because owners of essential patents oppose to changes in the standard that exclude their patents from the standard. We also discussed extensively the hypothesis that essential patents lead to more frequent upgrades of the standard, which would in turn delay standard obsolescence. While the inclusion of essential patents indeed increases the rate of standard upgrades, this effect alone is not sufficient to explain why standards including essential patents are less likely to be replaced. We further show that the effect of essential patents, even controlling for the rate of standard upgrade, is positively connected to a longer existence of standards.

Nevertheless, we would not argue based upon the presented evidence that essential patents lead to an inefficient lock-in of outdated standards. Indeed, essential patents seem to have a positive effect on the rate of standard upgrades. We have argued that these standard upgrades do not entail replacement of standard components, explaining why essential patents could induce standardizing firms to substitute standard upgrades for standard replacements. Essential patents do however not only induce standardizing firms to substitute standard upgrades for replacements, but also to overall increase the rate at which they revise standards (the sum of upgrades and replacements increases). The latter part of the finding can be explained by the fact that essential patents provide incentives for at least some standardizing firms to regularly invest into the standard in order to increase its value and associated royalty revenue, and to shield the standard from technological rivalry and replacement.

These findings have important implications for management and policy. For standard adopters, we argue that essential patents reduce the technological uncertainty associated with the adoption of a new standard. Users of a standard including essential patent benefit from increasing technological capacities through continuous improvements building upon a stable technological basis. Patents may thus signal the commitment of standard setting firms to continuously advance the standard. Furthermore, essential patents reduce the risk of standard replacement, thereby avoiding the loss of sunk investment in standard implementation. These beneficial effects should be weighed against the managerial risks arising from uncertainty about future levels of royalties.

For standard makers, the effects of essential patents can be controversially discussed based upon the presented evidence. Essential patents induce more frequent standard upgrades, but also inhibit standard replacement. On the one hand, standard upgrades do not seem to be as efficient as standard replacements in catching up to the technological frontier. Selecting patented technology can therefore inefficiently bind standard makers to a given technological trajectory, even when superior alternatives are available. On the other hand, standards referenced by other standards are also more likely to be upgraded rather than replaced. This could indicate that standard replacement entails significant social costs, including for adjustment of downstream applications and technologies building upon the standard. Essential patents, by substituting standard upgrades for replacements, could therefore reduce the cost of standard momentum for applications building upon the standard. The inclusion of essential patents thus reduces technological uncertainty and encourages users of the technology to incur costly and risky investments in standard implementation and complementary technology. These investments concur to the commercial and technological success of the standard.

Based upon this new analytical framework, we find a new justification for the argument that sponsorship of standards by a technology owner can act as an encouragement of standard adoption, and increase socially efficient investment building upon evolving standards. These effects of essential patents on the technological evolution of standards deserve more attention by policy makers currently working on a refinement of public rules for the treatment of patents in standardization in various legislations.

Conclusion

This dissertation addresses the lack of empirical evidence in the current economic literature on innovation and coordination in ICT standardization. I have built up and analyzed large databases of standards and patents, and I have found innovative ways to retrieve economic information from patent and standard statistics. My research has focused upon the role of essential patents, and how they interact with patent pools and informal standardization consortia. I have explored the effects of essential patents, patent pools and informal consortia along three research axes: the characteristics of essential patents, the number of patents filed in view of technological standards, and the rate of standard upgrades and replacements. In this concluding section, I will summarize the main findings of the thesis and their policy implications, and I will sketch opportunities for ongoing and future research.

1. Main results and policy implications

1.1 Essential patents are original incentive mechanisms tailored to distributed innovation

An important contribution of this dissertation is to provide empirical evidence for the particular characteristics and functions of essential patents. I have shown that for common patents in both discrete and complex technologies, there is a strong correlation between measures of the social value of the invention and the private value of the patent. This is consistent with the traditional analysis of the role of patents as incentive mechanism: an innovator receives a higher reward for a more valuable contribution. The patent system therefore streamlines innovation efforts towards the most valuable inventions to be made. This traditional story does however not hold for essential patents: within the sample of essential patents, patents on more significant or fundamental inventions are not more valuable for their owners. Compared with other patents, essential patents are however much more valuable and the inventions underlying essential patents are much more significant. SSOs select the inventions to be included into a standard, and inclusion into a standard greatly increases the return on the patent. The incentives induced by this mechanism differ from the incentives induced by common patents: rather than aiming at the most valuable invention, innovators have incentives to compete for inclusion of their patents into a standard, at the lowest possible cost and for the highest possible number of patents.

From a policy perspective, this finding corroborates concern regarding the increasing number of essential patents around technological standards. Indeed, there is a risk of a patent inflation, an increase in patenting on standard-essential technologies without an increase in the underlying inventive activity. The main addressee of this policy message are the patent offices, who need to further increase their efforts to guarantee the quality of patent applications in the context of standard development. The fact that essential patents on more significant inventions are not more valuable to their owners does however not mean that the system is ineffective. Essential patents are a specific incentive mechanism that streamlines R&D investments towards a joint innovation effort, and towards securing claims on the result of this joint effort. Policy needs to take this specific function of essential patents into account, and I therefore endorse the development that essential patents increasingly evolve to become sui generis appropriation mechanisms with particular rights and obligations. It needs however to be scrutinized whether the selection mechanism operating through standardization sets the adequate innovation incentives.

1.2 Companies can improve their yield in essential patents through membership in patent pools and informal consortia

In this dissertation, I analyze how the selection mechanism operating through standardization in SSOs is affected by strategic alliances. I explore how companies can increase the match of the standard with their patented technology through membership in patent pools and informal consortia. In the second research article, I show that founding and incumbent members of a patent pool are able to include into the pool a higher number of essential patents of lower significance. These companies thus are more successful in securing claims on the standard, for instance because their patents are more focused. It remains open whether this fact is a consequence of pool membership, or whether this finding indicates that pools tend to be initially founded by companies with an advantageous position in standard development. I also analyze consortia membership as a way to improve the focus of patents on the ongoing standardization. I empirically explore how this effect of consortia membership influences the overall social efficiency of patenting around technological standards.

These findings have important policy implications. Indeed, given the importance of SSOs as selection mechanism, potential capture of SSOs by single large companies or alliances of firms is a subject of concern for competition authorities, consumers and outside innovators. For instance the rising importance of informal consortia in formal standard development is not welcomed by all stakeholders alike. Examples of companies or alliances of companies "pushing their standard through a SSO" have repeatedly triggered much criticism (Egyedi, 2003). In other cases, evidence sheds light on strategies of companies to opportunistically and *ex post* privatize the returns of a social effort in the development of new standards (for instance through adjusting pending patent applications to ensure their match with ongoing standardization, Berger et al., 2012). In this context, my findings contribute two insights. On the one hand, I enlarge the circle of suspects. Indeed, my results suggest that not only consortia, but also patent pools could allow their members to increase the match between the standard and their patents. On the other hand, I present results which cast doubts on the alleged detrimental welfare consequences of this partial capture of standardization by alliances of firms. Indeed, even though in our model consortia membership increases the chances to obtain essential patents to the detriment of consortia outsiders, the empirical findings suggest that this streamlining or focusing of the R&D has socially beneficial effects on the volume of patent filings around technological standards.

1.3 Patent pools and informal consortia have a positive and beneficial effect on the number of patents filed around technological standards

One of the major methodological contributions of this dissertation is a detailed matching between standards and the technological classification of patents. This match allowed me to measure the extent of standard-related patenting, and to analyze the factors driving this figure. I have concentrated upon the effects of patent pools and informal consortia. Regarding patent pools, my analysis takes into account the fact that patent pools are to an overwhelming majority composed of patents on inventions made before pool creation. The interesting question is thus not how patenting evolves after a pool is created, but how patenting is affected by the fact that a pool is expected. In congruence with the predictions of the theoretical literature, I have found evidence for a positive effect of expected patent pool creation on the extent of patenting. I have furthermore highlighted that patenting takes place earlier with respect to standard development when a pool is expected. With respect to informal consortia, I have built my empirical analysis upon a theoretical model, which states that the effect of informal consortia depends upon whether essential patents induce sufficient incentives to invest in standard-related R&D. The empirical findings confirm these predictions, and reveal that consortia membership induces an increase in standard-related patenting when the R&D incentives are insufficient, and induces a more modest increase or even a decrease when R&D incentives are excessive. These findings point to a beneficial role of informal consortia in the coordination of standard-related R&D. They also have implications for public policy. My results overall endorse the recent permissive policy with respect to consortia and patent pools. Indeed, these mechanisms spur investment in standard-related R&D, even though the contribution of patent pools and consortia to the overall number of standard-related patents appears to be modest.

1.4 Essential patents induce more continuous and less discontinuous technological progress of standards

In the fifth research article, I have analyzed the effect of the inclusion of essential patents on the further technological progress of standards. I have distinguished between standard upgrades and standard replacement. Through standard upgrade, new functionalities are added to an existing standard, while through standard replacement existing standard functionalities are replaced by alternatives. Standard replacement thus potentially induces loss of backward compatibility and the exclusion of proprietary technology from the standard, but may be necessary to fully exploit the potential of a progressing technological state of the art. Controlling for the rate of technological progress, I have found that essential patents induce more frequent standard upgrades, but delay standard replacement. More frequent upgrades of existing standards contribute to longer standard survival, but cannot fully explain why standards including patents are less often replaced.

These novel findings have important implications for standard setters and standard adopters. For instance I argue that essential patents signal to potential standard adopters that a standard will be kept in place for a longer time and be continuously improved. Such a signal can encourage sunk investment in standard adoption and implementation (which in turn makes continuous progress of the standard yet more attractive relative to replacement). This mechanism illustrates the role of essential patents in the coordination between standard developers and implementers. But my results also reveal that the inclusion of essential patents delay standard replacement beyond the effect attributable to more frequent upgrades. This finding confirms that essential patents can induce excessive inertia in standardization, for instance through rent-seeking and conflicts of interest. Standard developers need to keep in mind that selecting patented technology for a standard also means to acquire the owner of this technology as a stakeholder in the standard. This stakeholder can play a beneficial role as a sponsor of the standard, investing in continuous improvements, but he can also block socially efficient innovation whenever it is contrary to his interests.

While my findings support solid management implications, I have so far not derived direct policy implications from my work on standard dynamics. Whether the role of essential patents in standard development is overall more beneficial than detrimental is a very important question from a policy perspective. My findings do however not allow concluding in either direction, because there is so far no empirically tractable model of the socially efficient rate of standard replacement. To advance towards such a model is one of the most important avenues for future research.

2. Opportunities for further research

This dissertation is the first analytical treatment of a novel and comprehensive database. My work on the database, on scientometric indicators and matching methodologies has already allowed me to address a series of important questions. Building upon the data and empirical methodologies as well as upon the analytical insights elaborated during this Ph.D. thesis, there are opportunities for fruitful further research. This research can proceed following three main lines: first, corroborate and generalize the results presented in this dissertation; second, address the questions left in suspension by the findings of my thesis; and third, explore potential applications of the insights of my research going beyond the field of my analysis.

2.1 Corroborate and generalize the results of my thesis: endogenize consortia and patent pools, observe technological rivalry

An important part of my dissertation deals with the effects of patent pools and informal consortia. In the different research articles, I discuss the fact that consortia and pools are more likely to be created for a specific kind of standards (for instance important standards with a high level of technological complexity), and that specific kinds of companies are more likely to join informal consortia and patent pools. I used various methodologies to avoid biases resulting from this endogeneity, for instance through eliminating sources of heterogeneity, sampling based upon observable characteristics, and by making use of exogenous policy changes. Nevertheless, a full understanding of the mechanisms and consequences of potential policy changes requires further progress in the analysis of the driving factors of these mechanisms. Only 45 patent pools have been created since 1997 for the thousands of standards including essential patents[101], and only a limited number of standards have been developed in conjunction with informal consortia. In order to evaluate whether consortia and pools could represent viable coordination tools for a larger share of standards including patents, future research will have to identify the driving factors and impediments for the creation and success of consortia and patent pools.

This research will also allow relaxing some of the stronger assumptions underlying my empirical research. For instance, by analyzing the factors which explain the creation and success of patent pools, it will be possible to make more appropriate approximations of the expectations of companies with respect to future pool creation. These better approximations would not only result in more reliable measures of the effect of a prospective pool creation on the patenting related to the particular standard, but also in estimations of the overall effect of the greater facility to create patent pools on patenting related to all ICT standards.

Another approximation which has proved helpful in my research is to use the participation of non-practicing entities to identify standards for which licensing income alone is a sufficient incentive to invest in R&D. In future research on the effects of R&D collaboration on standard development, it will be interesting to rely upon more direct measures of technological rivalry. As part of the research on this dissertation, I have contributed to build up a measure of the complementarity or substitutability of the patented technologies owned by the different firms participating in the development of a standard. In future research, this measure can be used

[101] our sample alone includes more than 700 ETSI specifications and 600 standards from other formal SDOs; to which an unknown number of standards at IETF and the numerous informal consortia has to be added

to analyze how technological rivalry affects incentives to collaborate, and to distinguish the effects of collaboration between rivals from the collaboration between firms contributing complementary assets.

2.2 Address the questions left open in this dissertation: what are the welfare implications of the inclusion of essential patents?

This dissertation has shed much light on the particular characteristics of essential patents, the coordination mechanisms used by companies to address the consequences of the increasing number of essential patents, and the consequences of essential patents for the choice between continuous and discontinuous progress of technological standards. These insights have set the basis for an investigation of the welfare implications of the inclusion of patented technology in a standard, and for instance the question whether essential patents induce excessive inertia in standard replacement. The core of this future investigation is an analysis of the empirically observed standard replacement rate with respect to the theoretical benchmark, i.e. the socially efficient rate of standard replacement which balances the discrete cost of replacement with the continuous opportunity cost of using inferior technology (or progressing along inferior technological trajectories). This is the research agenda of a project in collaboration with Prof. Reiko Aoki, Hitotsubashi University.

This research project has the clear ambition to make progress in the normative dimension of the analysis. We expect an empirical answer to the question whether ICT standardization in formal SSOs is characterized by too much inertia or too much momentum with respect to the social optimum. One of the most important deliverables of this research project will be to provide tractable guidance for the conduct of future standard development. For instance, we will investigate how IPR policies, SSO strategy and coordination among contributing firms can address problems of excessive inertia or momentum. These findings will hopefully inform decision making in emerging technological fields, and we will apply our analysis to precise case studies in close dialogue with practitioners.

2.3 Explore the applications of the insights of this dissertation outside the field of my analysis: implications of my findings for the economics of innovation and macroeconomics

This thesis has studied ICT standardization in formal SSOs. I have analyzed standardization as a more or less institutionalized selection mechanism in the context of cumulative innovation by distributed actors. Standardization is a variety reduction mechanism setting the basis for further progress, and coordinates investment in continuous and discontinuous technological change. This analysis can be applied to mechanisms well beyond the field of ICT. It would be interesting to explore potential applications of this analysis in other technological fields. To focus upon the institutions of standardization is a promising research avenue for economic research: indeed, if innovation is a conjunction of variety and standardization (of invention and selection), then standardization is probably the flip of the coin that economic analysis is better able to grasp. Economic agents cannot decide what to invent, but they can decide which technology to build upon. Standardization is the aspect of innovation which is endogenous to economic incentives and institutions, through standardization economics shapes the content of the future technology.

In a joint research project with Julia Schmidt (HEI Genève), I explore the macroeconomic implications of the economic function of standards. Our paper "Technological Standardization, Endogenous Productivity and Transitory Dynamics"[102] explores aggregate standard counts as a measure of technology shocks in a Real Business Cycle analysis. Standards represent the clustered adoption of bundles of inventions and set the technological basis for further innovative activity. We show that the adoption of new standards is endogenous to macroeconomic variables. Furthermore, we find that standardization is an important driver for investment and long-run productivity. However, following a positive shock in the number of standards, aggregate productivity temporarily decreases before picking up permanently. This finding is consistent with the analyzed tradeoff between the discrete cost and continuous benefit of technological progress in standards. Finally, this paper finds that standardization is an essential mechanism for anchoring technological expectations as evidenced by the positive reaction of stock market data to a standardization shock. We show that this reduction of uncertainty plays an important role for incentivizing further incremental innovation.

[102] http://www.eea-esem.com/eea-esem/2012/prog/viewpaper.asp?pid=2740, paper shortlisted for the 2012 FEEM award for the best paper of young economists by the European Economic Association

References

Abernathy W. J.; Utterback, J. M. (1978): Patterns of industrial innovation, *Technology Review*, Vol. 80(7)

Adelman I., Taft Morris C. (1965). A Factor Analysis of the Interrelationship Between Social and Political Variables and Per Capita Gross National Product. *The Quarterly Journal of Economics*, 79(4), 555-578

Aggarwal, N.; Dai, Q.; Walden, E. A. (2011): The More, the Merrier? How the Number of Partners in a Standard-Setting Initiative Affects Shareholder's Risk and Return, *MIS Quarterly*, (35: 2) pp.445-462

Allison, J., Lemley, M., Moore, K. and Trunkey, D. (2004): Valuable Patents, *Georgetown Law Journal*, Vol. 92, p. 435

Aoki, R., Nagaoka, S. (2004): The consortium standard and patent pools. *The Economic Review*, 55(4), pp. 346-356

Aoki, R.; Schiff, A. (2008): Promoting access to intellectual property: patent pools, copyright collectives, and clearinghouses, *R&D Management Journal,* 38(2), pp. 1467-9310

Arora, A., Ceccagnoli, M., Cohen, W. M. (2008): R&D and the patent premium, *International Journal of Industrial Organization*, Volume 26, Issue 5, 1153-1179

Arrow, K. (1962): Economic Welfare and the Allocation of Resources for Invention, *NBER Chapters*, in: The Rate and Direction of Inventive Activity: Economic and Social Factors, pages 609-626

Arthur, W.B. (1989): Competing Technologies, Increasing Returns, and Lock-In by Historical Events, *Economic Journal* 99, 116-131

Balcer, Y., Lippman, S. (1984): Technological expectations and adoption of improved technology, *Journal of Economic Theory*, 34(2), pp. 292–318

Bekkers, R. (2001): Mobile Telecommunications Standards: GSM, UMTS, TETRA and ERMES. Boston, MA: Artech House

Bekkers, R., Bongard, R., Nuvolari, A. (2011): An empirical study on the determinants of essential patent claims in compatibility standards, *Research Policy*, 40(7), pp. 1001–1015

Bekkers, R., Catalini, C., Martinelli, A., Simcoe, T. (2012): Intellectual Property Disclosure in Standards Development, *Conference Proceedings of the NBER conference on Standards, Patents & Innovation*

Bekkers R, Duysters G, Verspagen B. (2002): Intellectual property rights, strategic technology agreements and market structure. The case of GSM, *Research Policy,* 31, pp. 1141–1161

Bekkers, R., Martinelli, A. (2012): Knowledge positions in high-tech markets: Trajectories, standards, strategies and true innovators, *Technol. Forecast. Soc. Change* (in print)

Benner, M., Waldfogel, J. (2008): Close to you? Bias and precision in patent-based measures of technological position, *Research Policy*, 37, pp. 1556-1567

Berger F., Blind K., Thumm N. (2012): Filing behaviour regarding essential patents in industry standards. *Research Policy*, 41, pp.216– 225

Besen, S., Farrell. J. (1994): Choosing How to Compete: Strategies and Tactics in Standardization, *Journal of Economic Perspectives*, 8(2), pp. 117-131

Bessen, J. (2002): Estimates of patent rents from firm market value, *Research Policy*, 38, pp. 1604–1616

Bessen, J. (2004). Patent Thickets: Strategic Patenting of Complex Technologies. *Research on Innovation Working Paper*

Bessen, J. (2006). The value of U.S. patents by owner and patent characteristics. *Research on Innovation Working Paper*

Bessen, J., Hunt R. (2003). An Empirical Look at Software Patents, *Research on Innovation Working Paper* No. 03-17/R

Bessen, J., Maskin, E. (2006). Sequential Innovation, Patents, and Imitation. *MIT Dept. of Economics Working Paper* No. 00-01

Blind, K. (2004): The Economics of Standards: Theory, Evidence, Policy, Cheltenham, E. Elgar

Blind, K. (2007): Factors Influencing the Lifetime of Telecommunication and Information Technology Standards, *Journal of IT Standards & Standardization Research*, 5(1), 1-24, January-June 2007 1

Blind, K.; Bekkers, R.; Dietrich, Y.; Iversen, E.; Müller, B.; Pohlmann, T.; Verweijen, J. (2011): EU Study on the Interplay between Standards and Intellectual Property Rights (IPR), commissioned by the DG Enterprise and Industry

Blind, K., Egyedi, T. (2008): The Dynamics of Standards, Edward Elgar Publishing

Blind, K., Gauch, S. (2008): Trends in ICT standards: The relationship between European standardization bodies and standards consortia, *Telecommunications Policy*, 32, pp. 503–513

Blind, K. and Thumm, N. (2004): Interrelation between patenting and standardisation strategies: empirical evidence and policy implications, *Research Policy*, 33(10), pp. 1583-1598

Bloom, N., Schankerman, M., Van Reenen, J. (2010): Identifying technology spillovers and product market rivalry, *Working Paper*

Blundell, R., Griffith, R., Windmeijer, F. (2002): Individual Effects and Dynamic Feedback in Count Data Models. *Journal of Econometrics*, 87, pp. 115-143

Branstetter, L., Sakakibara, M. (2002): When Do Research Consortia Work Well and Why? Evidence from Japanese Panel Data, *American Economic Review*, 92(1), pp. 143-159

Bresnahan, T., Greenstein, S. (1999). Technological Competition and the Structure of the Computer Industry, *Journal of Industrial Economics*, 47(1), pp. 1-40

Bryson, A., Dorsett, R. and Purdon, S. (2002): The use of propensity score matching in the evaluation of labour market policies, *Working Paper* No. 4, Department for Work and Pensions

Caliendo, M., Kopeinig, S. (2008): Some Practical Guidance for the Implementation of Propensity Score Matching, *Journal of Economic Surveys*, Vol. 22, Issue 1, pp. 31-72

Cargill, C. (2002): Intellectual Property Rights and Standards Setting Organizations: An Overview of failed evolution, Report Issued By the U.S. Department of Justice and the Federal Trade Commission

Cargill, C., Weiss, M. (1992): Consortia in the Standards Development Process, *Journal of the American Society for Information Science*, 43(8), pp. 559 – 565

Chiao, B., Lerner, J., Tirole, J. (2007): The Rules of Standard Setting Organizations: An Empirical Analysis, *RAND Journal of Economics*, 38(4), pp. 905–930

Choi, J. P. (1994): Network Externality, Compatibility Choice, and Planned Obsolescence, *The Journal of Industrial Economics*, 42(2), pp. 167-182^

Choi, J.-P., (2011): Patent Pools and Cross-Licensing in the Shadow of Patent Litigation, *International Economic Review*, forthcoming

Choi, J.-P., (2012): Patent Pools and Innovation Incentives, *Working paper*

Christensen, C. M., Bower, J. L. (1996): Customer Power, Strategic Investment, and the Failure of Leading Firms, *Strategic Management Journal*, 17(3), 197-218

Christensen, C. M., Suárez, F. F., Utterback, J. M. (1998): Strategies for Survival in Fast-Changing Industries, *Management Science*, 44(12), 207-220

Clarkson, G. (2004): Objective Identification of Patent Thickets: A Network Analytic Approach for Measuring the Density of Patent Space, Ph.D. thesis, Harvard University

Clements, M. (2005): Inefficient Standard Adoption: Inertia and Momentum Revisited, *Economic Inquiry*, Vol. 43, 507-518

Cohen W., Nelson R., Walsh J. (2000). Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not), *NBER Working paper*

Cusumano, M., Gawer, A. (2002): The elements of platform leadership, *MIT Sloan Management Review*, Vol. 43, pp. 51-58

David, P., Greenstein, S. (1990): The Economics of Compatibility of Standards: A Survey, *Economics of Innovation and New Technology,* 1, pp. 3-41

David, P., Shurmer, M. (1996): Formal standards-setting for global telecommunications and information services. Towards an institutional regime transformation?, *Telecommunications Policy*, 20(10), pp.789-815

De Bijl, P., Goyal, S. (1995): Technological change in market with network externalities, International *Journal of Industrial Organization*, 12(3), pp. 307-325

DeLacey, B., Herman, K., Kiron, D., Lerner, J. (2006): Strategic Behavior in Standard-Setting Organizations, *Harvard NOM Working Paper* No. 903214

Delcamp, H., (2011-1), Essential patents in pools: Is value intrinsic or induced?, *Review of Industrial Organization*, forthcoming

Delcamp, H., (2011-2), Are patent pools a way to help patent owners enforcing their rights?, *Cerna Working Paper*

Delcamp, H., Leiponen, A. (2012): Innovating Standards Through Informal Consortia: The Case of Wireless Telecommunications, *NBER Working paper*

Dequiedt V, Versaevel B. (2012): Pools and the Dynamic Incentives to R&D. *Working paper*, under: http://ssrn.com/abstract=988303

Dosi, G. (1982): Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change, *Research Policy*, 11(3), 147–162.

Economides, N. (1996): The Economics of networks, *International Journal of Industrial Organization*, 14, pp. 673-699

Egyedi, T.M. (2003): Consortium Problem Redefined: Negotiating ’Democracy’ in the Actor Network on Standardization, *International Journal of IT Standards & Standardization Research*, 1(2), 22-38.

Egyedi, T.; Heijnen, P. (2005): Scale of Standards Dynamics: Change in formal, international IT standards – The Standards Edge: Future Generation, Bolin, S. (ed.): Bolin Communications.

Farrell, J., Klemperer, P. (2007): Coordination and Lock-In: Competition with Switching Costs and Network Effects, *Handbook of Industrial Organization*, 3, pp. 1967–2072.

Farrell, J., Saloner, G. (1985): Standardization, Compatibility and Innovation, *RAND Journal of Economics*, 16(1), pp. 70-83.

Farrell, J., Saloner, G. (1986): Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation, *American Economic Review*, 76(5), pp. 940-955.

Farrell, J., Saloner, G. (1988): Coordination through Committees and Marekts, *RAND Journal of Economics*, 19(2), pp. 235-252.

Farrell, J., Simcoe, T. (2011): Four Paths to Compatibility, in Waldfogel, J., Peitz, M. (eds): Oxford Handbook of the Digital Economy, forthcoming

Farrell, J., Simcoe, T. (2012): Choosing the Rules for Consensus Standardization, *RAND Journal of Economics,* forthcoming

Fleming, L., Waguespack, D. (2008): Scanning the Commons? Evidence on the Benefits to Startups Participating in Open Standards Development, *Management Science*, 55(2)

Fontana, R., Nuvolari, A,, Verspagen, B. (2009): Mapping Technological Trajectories as Patent Citation Networks. An Application to Data Communication Standards. *Economics of Innovation and New Technology*, 18, pp. 311-336.

Gauch, S. (2008): Dynamics and effects of competing standards of recordable DVD-media, in Egyedi, Blind (eds): The dynamics of standards, Cheltenham: Elgar, pp.47-67.

Garud, R., Jain, S., Kumaraswamy, A. (2002): Institutional Entrepreneurship in the Sponsorship of Common Technological Standards: The Case of Sun Microsystems and Java, *The Academy of Management Journal*, 45- 1, 196-214.

Ganglmair, B., Tarantino, E. (2012): Patent Disclosure in Standard Setting, *Conference Proceedings of the NBER conference on Standards, Patents & Innovation.*

Gawer A, Cusumano M. (2012): Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation, Boston, Massachusetts, Harvard Business School Press

Geradin, D. (2006): Standardization and Technological Innovation: Some Reflections on Ex-ante Licensing, FRAND, and the Proper Means to Reward Innovators, *World Competition*, 29, pp. 511 – 534

Gilbert R J. (2004): Anti-Trust for Patent Pools: A Century of Policy Evolution. *Stanford Technology Law Review* 3.

Gilbert R. (2009): The essentiality test for patent pools, in Dreyfuss, R., Zimmerman, D., and First, H. (eds.), Working within the Boundaries of Intellectual Property, Oxford University Press

Giummo J. (2003): Should All Patentable Inventions Receive Equal Protection? Identifying the Sources of Heterogeneity in Patent Value. *Discussion Paper*, University of California, Berkeley

Griliches Z. (1990): Patent statistics as economic indicators: a survey. *Journal of economic literature*, 28(4), pp.1661-1707

Hall, B. H., Jaffe, A. B., Trajtenberg, M. (2000): Market Value and Patent Citations: A First Look, *NBER Working Paper* No. 7741.

Hall, B. H., Jaffe, A., Trajtenberg, M. (2001): The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools, *NBER Working Paper* No. 8498

Hall B. H., Jaffe, A., Trajtenberg, M. (2005): Market value and patent citations. *RAND Journal of Economics*, 36, pp. 16-38

Hall, B. H., Ziedonis, R.H. (2001): The Patent Paradox Revisited: Determinants of Patenting in the U.S. Semiconductor Industry, 1980-94. *RAND Journal of Economics*, Vol. 32, pp. 101-128

Harhoff D., Narin F., Scherer F.M., Vopel K. (1999): Citation frequency and the value of patented inventions. *The Review of Economics and Statistics*, 81, 511-515

Harhoff, D., von Graevenitz, G., Wagner, S., (2008): Incidence and Growth of Patent Thickets - The Impact of Technological Opportunities and Complexity. *CEPR Discussion Papers* 6900

Hawkins, Richard (1999) : The rise of consortia in the information and communication technology industries: emerging implications for policy, *Telecommunications Policy*, 23(2), pp. 159-173.

Heckman, J., Ichimura, H. and Todd, P. (1998): Matching as an econometric evaluation estimator, *Review of Economic Studies,* 65(2), pp. 261–294

Heckman, J., Robert, J., LaLonde, J., Smith J. S. (1999): The Economics and Econometrics of Active Labour Market Programs, in O. Ashenfelter and D. Card (Eds.), The Handbook of Labour Economics, vol. III

Iizuka, T. (2007): An Empirical Analysis of Planned Obsolescence, *Journal of Economics & Management Strategy*, 16- 1, 1530-9134

Jaffe, A., Lerner, J. (2004). Innovation and Its Discontents. Princeton University Press

Joshi, A. M., Nerkar, A. (2011-1): When do strategic alliances inhibit innovation by firms? Evidence from patent pools in the global optical disc industry, *Strategic Management Journal* 32(11), pp. 1097-0266

Joshi, A., Nerkar, A., (2011-2): Which Technologies Get Put Up for Sale and Why? Knowledge Asset Recombinations as a Predictor of Outbound Licensing, *Journal of Marketing*, forthcoming

Katz, M., Shapiro, C. (1986): Technology Adoption in the Presence of Network Externalities, *Journal of Political Economy* , 94(4), pp. 822-841.

Katz, M., Shapiro, C. (1992): Product Introduction with Network Externalities, *Journal of Industrial Economics*, 40(1), pp. 55-84.

Kindleberger, C. P. (1983): Standards as public, collective, and private goods, Kyklos Vol. 36, pp. 377-397.

Kitch, E. (1977): The Nature and Function of the Patent System, *Journal of Law and Economics*, 20(2), pp. 265-290.

Klemperer, P. (1990): How Broad Should the Scope of Patent Protection Be?, *RAND Journal of Economics*, Vol. 21(1), pp. 113-130

Kristiansen, E (1998): R&D in the presence of network externalities: timing and compatibility, *RAND Journal of Economics*, 29, pp. 531-547.

Lampe, R., Moser, P. (2010): Do Patent Pools Encourage Innovation? Evidence from the 19th century Sewing Machine Industry. *Journal of Economic History,* 70, pp. 898-920.

Lampe, R., Moser, P. (2011): Patent Pools and Innovation in Substitutes - Evidence from the 19th Century Sewing Machine Industry, *Working paper*

Lampe, R., Moser, P. (2012): Do Patent Pools Encourage Innovation. Evidence from the eight industries in the 1930ies. *NBER working paper*

Lanjouw, J., Pakes, A., Putnam, J. (1998): How to Count Patents and Value Intellectual Property: Uses of Patent Renewal and Application Data. *Journal of Industrial Economics*, XLVI(4), pp. 405-433

Lanjouw, J., Schankerman, M. (1999): The quality of ideas: measuring innovation with multiple indicators, *NBER Working Paper*

Lanjouw J., Schankerman, M. (2004): Patent quality and research productivity: measuring innovation with multiple indicators. *Economic journal*, pp. 114 (495), pp. 441-465

Layne-Farrar A. (2008): Innovative or Indefensible? An Empirical Assessment of Patenting within Standard Setting, *International Journal of IT Standards Research,* 9(2), pp. 1-18.

Layne-Farrar, A., Lerner, J. (2011): To join or not to join: Examining patent pool participation and rent sharing rules, *International Journal of Industrial Organization*, 29(2), pp. 294-303.

Layne-Farrar, A., Llobet, G., Padilla, J. (2011): Payments and Participation: The Incentives to Join Cooperative Standard Setting Efforts, Working Paper

Leiponen, A., (2008): Competing Through Cooperation: The Organization of Standard Setting in Wireless Telecommunications, *Management Science*, 54(11), pp. 1904-1919.

Lemley, M. (2002): Mark A. Lemley, Intellectual Property Rights and Standard-Setting Organizations, *California Law Review* 90, pp. 1889-1980

Lemley, M., Shapiro, C. (2006): Patent Holdup and Royalty Stacking, *Texas Law Review* 81, pp. 1991-2044

Lerner, Strojwas, Tirole, (2007), The Design of Patent Pools: the Determinants of Licensing Rules, *RAND Journal of Economics,* 38(3), pp. 611-625

Lerner, J, Tirole, J. (2004): Efficient Patent Pools, *American Economic Review*, 94(3), pp. 691-711.

Lerner, J, Tirole, J. (2006): A Model of Forum Shopping, *American Economic Review*, 96, pp. 1091-1113.

Lévêque, F., and Ménière, Y., (2008): Vagueness in RAND Licensing Obligations is Unreasonable for Patent Owners, *Working Paper*

Lévêque, F., and Ménière, Y., (2011): Patent pool formation: Timing matters, *Information Economics and Policy*, 23(3-4), pp. 243-251

Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., Gilbert, R., Griliches, Z. (1987): Appropriating the Returns from Industrial Research and Development. *Brookings Papers on Economic Activity: Special Issue On Microeconomics*, pp. 783-831

Liebowitz, S., Margolis, S. (2005): Path Dependence, Lock-In and History, *Journal of Law, Economics and Organization*, 11(1), pp. 205-26

Liu, K., Arthurs, J., Cullen, J., Alexander, R. (2008): Internal sequential innovations: How does interrelatedness affect patent renewal? *Research Policy*, 37(5), 946-953

Llanes, G., Trento, S. (2010): Patent policy, patent pools, and the accumulation of claims in sequential innovation, *Economic Theory*, forthcoming

Matutes, C., Regibeau, C. (1992): Compatibility and bundling of complementary goods in a duopoly, Journal of Industrial Economics, 40, pp. 37-50

McGrath, G., Nerkar, A. (2004): Real options reasoning and a new look at the R&D investment strategies of pharmaceutical firms, *Strategic Management Journal*, 25: 1–21.

Merges R. P., Nelson R. (1990): On the Complex Economics of Patent Scope. *Columbia Law Review*. 90(4), pp. 839-916

Metcalfe, S., Miles, I. (1994): Standards, Selection and Variety: An Evolutionary Approach, *Information Economics and Policy*, 6(3-4), pp. 243-268

Nagaoka, S., (2005): Patent quality, cumulative innovation and market value: Evidence from Japanese firm level panel data. *IIR Working Paper* 05-06. Institute of Innovation Research. Hitotsubashi University

Nagaoka, S., Tsukada, N. and Shimbo, T. (2009): The structure and the emergence of essential patents for standards: Lessons from three IT standards, *Schumpeterian perspectives on innovation, competition and growth,* 4, 435-450.

Noel, M., Schankerman, M. (2006). Strategic Patenting and Software Innovation, *LSE Research Paper* No. EI43

Parchomovsky, G., Polk Wagner, R. (2005): Patent Portfolios. *University of Pennsylvania Law Review* 154(1), pp. 1-54

Park, G., Park, Y. (2006): On the measurement of patent stock as knowledge indicators, *Technological Forecasting and Social Change,* 73, pp. 793-812.

Peters, R. (2011): One-Blue: a blueprint for patent pools in high-tech, *Intellectual Asset Management*, September/October, pp. 38-41.

Pohlmann, T. (2010): Attributes and Dynamic Development Phases of Informal ICT Standards Consortia, *TUB Working Paper*

Pohlmann, T., Blind, K. (2012): Cooperate to Declare. Firms' cooperative activities as driving factors of patent declaration on technological standards, *TUB working paper*

Putnam, J. (1996), The value of international patent rights, Ph.D. Thesis, Yale University

Reitzig, M. (2004), Improving patent valuations for management purposes - validating new indicators by analyzing application rationales, *Research Policy*, 33, pp. 939–957

Rosenbaum, P. (1987): The Role of a Second Control Group in an Observational Study, *Statistical Science* , 2(3), pp. 292-306.

Rysman, M., Simcoe. T. (2008): Patents and the Performance of Voluntary Standard Setting Organizations, *Management Science*, 54(11), pp. 1920-1934.

Rysman, M., Simcoe. T. (2012): A NAASTy Alternative to RAND Pricing Commitments, *Telecommunications Policy*, forthcoming

Salant, D. (2009): Formulas for Fair, Reasonable, and Non-Discriminatory Royalty Determination. *International Journal of IT Standards and Standardization Research*. 7(1), pp. 66-75

Schmidt, Klaus M. (2010): Standards, Innovation Incentives, and the Formation of Patent Pools. *SFB/TR 15 Discussion Paper* No. 342

Shapiro, C. (2001): Navigating the Patent Thicket: Cross Licenses, Patents Pools, and Standard Setting. In: A Jaffe, J Lerner et S, Stern (Eds), *Innovation Policy and the Economy*, vol. 1. MIT Press.

Simcoe, T. (2007): Explaining the Increase in Intellectual Property Disclosure, in Standards Edge: The Golden Mean. Bolin Group, pp. 260-295

Simcoe, T. (2012): Standard Setting Committees: Consensus Governance for Shared Technology Platforms, *American Economic Review*, 102(1), pp. 305-336.

Smith, J., Todd, P. (2005): Does matching overcome LaLonde's critique of non-experimental estimators? *Journal of Econometrics,* 125(2), pp. 305–353.

Suarez, F. (2005): Network Effects Revisited: The Role of Strong Ties in Technology Selection, *The Academy of Management Journal*, Vol. 48, No. 4 (Aug., 2005), pp. 710-720.

Swanson, D., Baumol, W. (2005). Reasonable and Nondiscriminatory (RAND) Royalties, Standards Selection, and Control of Market Power. *Antitrust Law Journal*, 73

Tassey, G. (2000): Standardization in technology-based markets, *Research Policy*, 29(4-5), pp. 587-602

Thoma G., S. Torrisi, Gambardella, A., Guellec, D., Hall, B. H., Harhoff, D. (2010): Harmonizing and Combining Large Datasets – An Application to Firm-Level Patent and Accounting Data, *NBER Working Paper* No. 15851

Thomas, P. (1999): The Effect of Technological Impact upon Patent Renewal Decisions. *Technology Analysis & Strategic Management*. 11(2), pp. 181-197.

Trajtenberg, M. (1990-1): A penny for your quotes: patent citations and the value of innovations, *RAND Journal of Economics*, 21(1), pp. 171-187.

Trajtenberg, M. (1990-2): Economic Analysis of Product Innovation: The Case of CT Scanners, Harvard University Press

Trajtenberg, M., Henderson, R., Jaffe, A. (1997): University versus Corporate Patents: A Window on the Basicness of Invention. *Economics of Innovation and New Technology*. 55(1), pp. 19 – 50

Updegrove, A. (1995): Consortia and the Role of the Government in Standard Setting, in B. Kahin & J. Abbate (Eds.). Standards Policy for Information Infrastructure, Cambridge: MIT Press, pp. 321-348

van Zeebroeck, N., van Pottelsberghe de la Potterie, B. (2011): The vulnerability of patent value determinants, *Economics of Innovation and New Technology*, 20(3), pp. 283 — 308

Von Graevenitz, G., Wagner, S., Harhoff, D. (2009): How to measure patent thickets: a novel approach, *Discussion Papers in Business Administration* 10962. University of Munich. School of Management

Wajima, K., Inuzuka, A., Watanabe, T. (2010): Empirical Study on Essential Patents in DVD and MPEG Patent Pools, *IAM Discussion Paper Series* #016

Waldman, M. (1993): A new perspective on planned obsolescence, *Quarterly Journal of Economics,* 108, 273–84.

Weitzel, T., Beimborn, D., König, W. (2006): A unified economic model of standard diffusion: The impact of standardization cost, network effects and network topology, *MIS Quarterly, 30, Special Issue, pp. 489-514*

West, J. (2003): How Open is Open Enough? Melding Proprietary and Open Source Platform Strategies, *Research Policy,* 32(7), pp. 1259-1285.

West, J., Dedrick, J. (2000): Innovation and Control in Standards Architectures: The Rise and Fall of Japan's PC-98, *Information Systems Research*, 11(2), pp. 197-216.

Appendix

Chapter I

Appendix 1

The following table summarizes the results of a principal factor analysis of the four main indicators of patent quality used by Lanjouw and Schankerman (2004)

	Complex technologies Sample 2		Discrete technologies Sample 3	
Variance	0.31715	0.23077	0.52903	0.07807
Allnscites	0.3053	0.1541	0.4456	0.1267
Cmade	0.2875	0.3087	0.3543	0.1614
Claims	0.3462	0.1783	0.2311	0.1825
Familysize	0.1464	0.2827	0.3893	0.0518
Number of observations	*3004*		*3139*	

Table 5: Factor analysis four indicators

Appendix 2

List 1 : list of discrete technology classes

19	Textiles: Fiber Preparation
26	Textiles: Cloth Finishing
28	Textiles: Manufacturing
29	Metal Working
38	Textiles: Ironing or Smoothing
44	Fuel and Related Compositions
57	Textiles: Spinning, Twisting, and Twining
66	Textiles: Knitting
68	Textiles: Fluid Treating Apparatus
71	Chemistry: Fertilizers
75	Specialized Metallurgical Processes, Compositions for Use Therein, Consolidated Metal Powder Compositions, and Loose Metal Particulate Mixtures
76	Metal Tools and Implements, Making
87	Textiles: Braiding, Netting, and Lace Making
99	Foods and Beverages: Apparatus
100	Presses
101	Printing
135	Tent, Canopy, Umbrella, or Cane
139	Textiles: Weaving
148	Metal Treatment
162	Paper Making and Fiber Liberation
164	Metal Founding
228	Metal Fusion Bonding
229	Envelopes, Wrappers, and Paperboard Boxes
423	Chemistry of Inorganic Compounds
424	Drug, Bio-Affecting and Body Treating Compositions
429	Chemistry: Electrical Current Producing Apparatus, Product, and Process
435	Chemistry: Molecular Biology and Microbiology
436	Chemistry: Analytical and Immunological Testing
514	Drug, Bio-Affecting and Body Treating Compositions
518	Chemistry: Fischer-Tropsch Processes; or Purification or Recovery of Products Thereof
585	Chemistry of Hydrocarbon Compounds

List 2: list of technology classes of essential patents

Class	Description of the class	Discrete	Complex
8	Bleaching and Dyeing; Treatment of Textiles and Fibers	1	0
16	Miscellaneous Hardware	1	0
29	Metal Working	1	0
36	Boots, Shoes, and Leggings	1	0
40	Card, Picture, or Sign Exhibiting	0	1
73	Measuring and Testing	0	2
75	Specialized Metallurgical Processes	1	0
84	Music	2	0
105	Railway Rolling Stock	1	0
119	Animal Husbandry	1	0
169	Fire Extinguishers	1	0
174	Electricity: Conductors and Insulators	0	3
178	Telegraphy	0	1
188	Brakes	1	0
211	Supports: Racks	1	0
235	Registers	0	14
250	Radiant Energy	0	1
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	1	0
264	Plastic and Nonmetallic Article Shaping or Treating: Processes	1	0
283	Printed Matter	1	0
315	Electric Lamp and Discharge Devices: Systems	1	0
324	Electricity: Measuring and Testing	0	7
326	Electronic Digital Logic Circuitry	0	4
327	Miscellaneous Active Electrical Nonlinear Devices, Circuits, and Systems	0	1
329	Demodulators	0	1
330	Amplifiers	0	7
331	Oscillators	0	3
332	Modulators	0	1
333	Wave Transmission Lines and Networks	0	2
335	Electricity: Magnetically Operated Switches, Magnets, and Electromagnets	0	1
340	Communications: Electrical	0	73
341	Coded Data Generation or Conversion	0	48
342	Communications: Directive Radio Wave Systems and Devices (e.g., Radar)	0	51
343	Communications: Radio Wave Antennas	0	1
345	Computer Graphics Processing, Operator Interface Processing …	0	13
346	Recorders	0	1
347	Incremental Printing of Symbolic Information	3	0
348	Television	0	102
351	Optics: Eye Examining, Vision Testing and Correcting	0	1
358	Facsimile and Static Presentation Processing	0	99
359	Optics: Systems (Including Communication) and Elements	0	17
360	Dynamic Magnetic Information Storage or Retrieval	0	9
361	Electricity: Electrical Systems and Devices	0	2
362	Illumination	2	0
365	Static Information Storage and Retrieval	0	4
367	Communications, Electrical: Acoustic Wave Systems and Devices	0	1
369	Dynamic Information Storage or Retrieval	0	278
370	Multiplex Communications	0	588
375	Pulse or Digital Communications	0	333
379	Telephonic Communications	0	85
380	Cryptography	0	109
381	Electrical Audio Signal Processing Systems and Devices	0	19
382	Image Analysis	0	87
385	Optical Waveguides	0	4
386	Television Signal Processing for Dynamic Recording or Reproducing	0	225

395	Information Processing System Organization	0	120
401	Coating Implements with Material Supply	1	0
423	Chemistry of Inorganic Compounds	1	0
428	Stock Material or Miscellaneous Articles	6	0
430	Radiation Imagery Chemistry: Process, Composition, or Product Thereof	4	0
434	Education and Demonstration	1	0
435	Chemistry: Molecular Biology and Microbiology	1	0
436	Chemistry: Analytical and Immunological Testing	2	0
438	Semiconductor Device Manufacturing: Process	0	1
439	Electrical Connectors	0	13
455	Telecommunications	0	307
473	Games Using Tangible Projectile	0	1
514	Drug, Bio-Affecting and Body Treating Compositions	2	0
524	Synthetic Resins or Natural Rubbers -- Part of the Class 520 Series	1	0
568	Organic Compounds -- Part of the Class 532-570 Series	1	0
604	Surgery	0	1
606	Surgery	0	1
700	Data Processing: Generic Control Systems or Specific Applications	0	2
701	Data Processing: Vehicles, Navigation, and Relative Location	0	4
702	Data Processing: Measuring, Calibrating, or Testing	0	7
704	Data Processing: Linguistics, Audio Compression/Decompression	0	64
705	Data Processing: Financial, Business Practice, Management	0	1
707	Data Processing: Database and File Management, Data Structures	0	16
708	Electrical Computers: Arithmetic Processing and Calculating	0	4
709	Electrical Computers and Digital Processing Systems: Multiple Computer	0	41
710	Electrical Computers and Digital Data Processing Systems: Input/Output	0	11
711	Electrical Computers and Digital Processing Systems: Memory	0	12
713	Electrical Computers and Digital Processing Systems: Support	0	24
714	Error Detection/Correction and Fault Detection/Recovery	0	75
		41	2904

Appendix 3

List 3: list of patent pools in our sample	List 4: list of Standard Development Organizations in our sample
▪ 1394 ▪ DVD 6C ▪ MPEG 2 ▪ MPEG 4 Systems ▪ MPEG 4 Visual ▪ AVC ▪ DVB-T	▪ American National Standard Institute ▪ Alliance for Telecommunications Industry Standards ▪ European Telecommunications Standards Institute ▪ Institute for Electrical and Electronic Engineering ▪ Internet Engineering Task Force, ▪ International Organization for Standards International Electrotechnical Commission ▪ International Telecommunications Union ▪ Telecommunications Industry Association

Appendix 4

We inform the concrete technological standard that 1.509 patents are essential to and the dates of disclosure. If one patent is disclosed as essential to several standards, we retain only the standard of the first disclosure. For every standard, we calculate the mean of the disclosure dates of all essential patents. For every patent, we generate an *age_of_disclosure* variable, defined as the difference between the disclosure date and the mean disclosure date for this particular standard. For the 993 pool patents, we use an earlier database including an *age_of_input* variable, defined as the difference between the date of input of a given patent and the date of input of the first patent in the pool. Even though differently constructed, age_of_disclosure and age_of_input both allow studying the chronological order of patents that are essential for the same technology.

We created two new variables, *founding patent pool*, which equals 1 if the patent is a pool founding patent and *founding_patent_sso* which equals 1 if the patent was disclosed before the average age of patent disclosure to the respective standard. These variables allow us to discriminate between fundamental and incremental innovations. The underlying assumption is that founding patents of a pool or a standardization project are more fundamental. We run a regression with the two variables *founding patent pool* and *founding_patent_sso* as explained variable and the factors highlighted in section III as the explanatory variables.

Probit	Founding patent SSO	Founding patent pool
Basicness factor	0.24172*** (0.127)	0.25693* (0.127)
Impact factor	0.53371*** (0.196)	0.50440** (0.196)
Age effect	0.08696* (0.094)	0.16499 (0.094)
Dummy Assignee control	Y	Y
_cons	-173.9146* (187.164)	- 327.8643 (187.164)
Number of obs	*2601*	*369*
Wald chi2(22)	*217.33*	*86.89*
Prob > chi2	*0*	*0*

legend: * p<0.05; ** p<0.01; *** p<0.001
Robust standard erros in parentheses

Table 6: Interpretation basicness factor

Appendix 5

	Sample 1 : Essential, very cumulative patents				Sample 2 : Complex technology classes				Sample 3 : Discrete technology classes			
	Litigated		Renewed after 8 years		Litigated		Renewed after 8 years		Litigated		Renewed after 8 years	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Forward citations	-0,001 (0.001)	-0,001 (0.001)	-0,001 (0.001)	-0,001 (0.001)	0,005*** (0.001)	0.005*** (0.0636)	0,006*** (0.002)	0.005** (0.0154)	0.008* (0.003)	0.009*** (0.0293)	0.007** (0.002)	0.011*** (0.0120)
Backward citations	-0,003 (0.004)	-0,003 (0.004)	-0,003 (0.004)	-0,003 (0.004)	0,010* (0.004)	0.008** (0.0382)	-0,004 (0.003)	0.002 (0.0003)	-0.013 (0.008)	-0.004 (0.0105)	-0.005 (0.003)	0.003 (0.0003)
Claims	0,005 (0.004)	0,005 (0.004)	0,005 (0.004)	0,005 (0.004)	0,001 (0.008)	0.013** (0.0361)	0,012** (0.004)	0.014** (0.0114)	0.005 (0.006)	0.006 (0.0099)	0.007 (0.003)	0.008** (0.0037)
Originality	0,889* (0.352)	0,889* (0.352)	0,889* (0.352)	0,889* (0.352)	0,770 (0.513)	0.571 (0.0234)	-0,010 (0.008)	-0.113 (0.0004)	-0.708 (0.539)	-0.240 (0.0242)	-0.286 (0.136)	-0.173 (0.0007)
Generality	0,026 (0.229)	0,026 (0.229)	0,026 (0.229)	0,026 (0.229)	0,668 (0.568)	0.506* (0.0224)	-0,116 (0.101)	0.109 (0.0007)	0.211 (0.290)	0.229 (0.0128)	0.233 (0.093)	0.300** (0.0057)
Family size	0,001 (0.001)	0,001 (0.001)	0,001 (0.001)	0,001 (0.001)	0,004 (0.002)	0.006* (0.0365)	0,023** (0.015)	0.014 (0.0078)	0.001 (0.001)	0.001* (0.0098)	0.007* (0.002)	0.012*** (0.0147)
Age control	Y	Y	Y	Y	Y	Y			Y	Y		
Control Assignee	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Number of observations	3191	3191	3191	3191	3004	3004	3004	3004	2853	2853	2853	2853

legend: * p<0.05; ** p<0.01; *** p<0.001

Table 7: The impact of single patent quality indicators on patent value, as measured by litigation and renewal

Chapter II

Appendix 1

Nationality of the first patent introduced into the pool	Not-Mixed patent family*	Mixed patent family*
US	380	111
JP	1181	29
both	0	95
Sum	1561	235
*	Pool includes US or Japanese patent	Pool includes US and Japanese patent

Table 6 Patent families including US and Japanese Patents, Order of Introduction

Appendix 2

Variable	*Description*	*Mean*	*Std. Dev.*	*Min*	*Max*
Variables regarding patent					
Appyear	Year patent applied for	1998.23	3.96	1981	2006
Gyear	Year patent granted	2000.42	4.02	1983	2006
Nclass	U.S. patent technology class (3 digit)				
Allnscites	Total cites flow (truncation corrected) from other companies	17.92	29.40	0	251.33
Genindex	Generality of the patent (NBER U.S. database)	0.33	0.37	0	1
Claims	Number of claims for the patent	4.94	9.61	1	99
Family_size	Family size for the patent calculated from espacenet	30.37	83.24	1	700
Variables regarding the timing					
Age_input	Age of the input calculated from the pool creation date (in months)	40.26	29.52	0	139
Number_input	Chronological number of input into this pool	2.69	2.27	0	11
Variables regarding the patent essentiality					
Sections	Number of standard sections for which the patent is cited	4.24	2.91	1	24
Subsections	Number of standard subsections for which the patent is cited	13.88	10.84	1	88
Sections corrected	Number of standard sections for which the patent is cited / median number of standard sections	1.41	0.95	.25	8.73
Subsections corrected	Number of standard subsections for which the patent is cited / median number of standard subsections	1.41	0.95	.25	8.73

Table 7 Summary Statistics

Appendix 3

			Citations	Claims	Generality	Family Size	Essentiality scope
DVD6C	Late joiners (0)	Mean Obs.	14.5855 95	21.9705 102	0.1149 34	19.8055 36	1.2529 101
	Founding members (1)	Mean Obs.	15.2485 752	14.1103 752	0.2258 426	15.5105 476	1.5970 754
	t-statistics	t Pr(T < t) Pr(T > t)	-0.2284 0.4097 0.5903	4.9257 1.0000 0.0000	-1.9577 0.0254 0.9746	0.7198 0.7640 0.2360	-3.1270 0.0009 0.9991
MPEG2	Late joiners (0)	Mean Obs.	48.4778 46	14.1914 47	0.7275 41	15.0222 45	1.2142 42
	Founding members (1)	Mean Obs.	36.52598 62	15.6153 65	0.6499 53	13.4482 58	1.1293 58
	t-statistics	t Pr(T < t) Pr(T > t)	1.3706 0.9133 0.0867	-0.6069 0.2726 0.7274	1.4752 0.9282 0.0718	0.8046 0.7885 0.2115	0.9438 0.8262 0.1738
MPEG4 Visual	Late joiners (0)	Mean Obs.	37.0503 9	28.8888 9	0.6002 4	13.4 5	1 8
	Founding members (1)	Mean Obs.	12.9227 122	14.9927 138	0.3609 74	13.3703 81	.8547 117
	t-statistics	t Pr(T < t) Pr(T > t)	3.1961 0.9991 0.0009	2.6560 0.9956 0.0044	1.2390 0.8904 0.1096	0.0055 0.5022 0.4978	1.1568 0.8752 0.1248
AVC H.264	Late joiners (0)	Mean Obs.	26.8134 18	20.5294 51	0.6751 5	11.8 5	0.9242 22
	Founding members (1)	Mean Obs.	10.8593 48	22.2112 71	0.4946 21	13.7083 24	1.0340 49
	t-statistics	t Pr(T < t) Pr(T > t)	2.0946 0.9799 0.0201	-0.3712 0.3556 0.6444	0.9271 0.8184 0.1816	-0.3978 0.3470 0.6530	-1.0973 0.1382 0.8618

Table 8 T-test patent indicators late joiners vs. founding members, by pool

Appendix 4

	(1) NBREG	(2) NBREG	(3) Poisson
	DV=Number of claims	**DV=Number of citations**	**DV=Number of standard sections**
Outsiders*	6.090**	1.646***	-0.222**
	(3.109)	(0.479)	(0.099)
Founding Patent*	1.228	0.005	-0.023
	(2.281)	(0.328)	(0.166)
Age input	-0.053	-0.008	0.002
	(0.035)	(0.006)	(0.002)
Number of claims		0.015***	0.001
		(0.004)	(0.002)
Patent technological classes	Y	Y	Y
Patent age effect	Y	Y	Y
Pool dummies	Y	Y	Y
Observations	1208	1208	1143
Nb. of clusters	190	190	162

*Legend: * p<0.10; ** p<0.05; *** p<0.01. Robust standard error clustered in parentheses.*
(*) dy/dx is for discrete change of dummy variable from 0 to 1

Table 9. Marginal effects controlling for the technological classes

Appendix 5

	(1) NBREG	(2) NBREG	(3) NBREG	(4) NBREG	(5) NBREG	(6) Poisson	(7) Poisson
	DV=Number of claims	**DV=Generality index**		**DV=Number of citations**		**DV=Number of standard sections**	
Outsiders	0.385***	0.212*	0.201	0.821***	0.745***	-0.192**	-0.194**
	(0.135)	(0.131)	(0.132)	(0.179)	(0.191)	(0.098)	(0.097)
Founding Patent	0.126	0.587***	0.579***	0.203	0.144	0.009	0.006
	(0.130)	(0.152)	(0.155)	(0.182)	(0.189)	(0.123)	(0.124)
Age input	-0.003	0.005*	0.005*	-0.004	-0.003	0.0005	0.0005
	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)	(0.002)	(0.002)
Number of claims			0.005**		0.011***		0.001
			(0.002)		(0.004)		(0.002)
Patent age effect	Y	Y	Y	Y	Y	Y	Y
Pool dummies	Y	Y	Y	Y	Y	Y	Y
Obervations	1208	707	707	1229	1208	1164	1143
Number of clusters	190	141	141	190	190	162	162
Pseudolikelihood	-4463.72	-368.48	-366.39	-4028.52	-3992.41	-1529.91	-1503.78

Legend: * p<0.10; ** p<0.05; *** p<0.01. *Robust standard error clustered in parentheses.*

Table 10. Regression results negative binomial, coefficients

	(1) OLS REG	(2) OLS REG	(3) OLS REG	(4) OLS REG	(5) OLS REG	(6) OLS REG	(7) OLS REG
	DV=Number of claims	**DV=Generality index**		**DV=Number of citations**		**DV=Number of standard sections**	
Outsiders	6.565***	0.051	0.040	7.922***	7.151**	-0.261*	-0.264*
	(2.354)	(0.041)	(0.043)	(2.862)	(3.132)	(0.139)	(0.138)
Founding Patent	2.430	0.210***	0.206***	-0.110	-0.528	0.010	0.006
	(2.262)	(0.040)	(0.042)	(3.505)	(3.586)	(0.172)	(0.174)
Age input	-0.045	0.001*	0.001*	-0.100**	-0.095*	0.0007	0.0008
	(0.036)	(0.0006)	(0.0006)	(0.050)	(0.049)	(0.002)	(0.002)
Number of claims			0.001*		0.163***		0.002
			(0.0007)		(0.055)		(0.003)
Patent age effect	Y	Y	Y	Y	Y	Y	Y
Pool dummies	Y	Y	Y	Y	Y	Y	Y
Obervations	1208	707	707	1229	1208	1164	1143
Number of clusters	190	141	141	190	190	162	162
R-squared	0.08	0.55	0.55	0.32	0.33	0.08	0.08

Legend: * p<0.10; ** p<0.05; *** p<0.01. *Robust standard error clustered in parentheses.*

Table 11. Regression results OLS, coefficients

Appendix 6

	(1) NBREG	(2) NBREG
	DV= Number of citations	**DV=Number of citations**
	Coefficients	Marginal effects
Outsiders*	0.787***	5.131***
	(0.159)	(1.381)
Founding Patent*	0.070	0.337
	(0.207)	(1.016)
Age input	-0.003	-0.015
	(0.004)	(0.017)
Patent linear age effect	0.126**	0.592**
	(0.055)	(0.274)
Patent technological classes	Y	Y
Application year dummies	Y	Y
Pool dummies	Y	Y
Observations	1229	1229
Nb. of clusters	190	190
Pseudolikelihood	-4011.92	

*Legend: * p<0.10; ** p<0.05; *** p<0.01. Robust standard error clustered in parentheses.*
(*) dy/dx is for discrete change of dummy variable from 0 to 1

Table 12. Regression results controlling for the application years, technological classes and age of the patent

Appendix 6

	(1)	(2)	(3)	(4)
	NBREG	NBREG	NBREG	NBREG
	Generality index	**Number of citations**	**Number of standard sections**	**Number of claims**
Outsiders_MPEG2	-0.252	0.079	0.082	-0.083
	(0.179)	(0.403)	(0.086)	(0.302)
Outsiders_MPEG4 Visual	0.889**	1.787***	0.182	0.934***
	(0.433)	(0.615)	(0.152)	(0.224)
Outsiders_DVD6C	0.343	0.790***	-0.250**	0.660***
	(0.265)	(0.194)	(0 .107)	(0.171)
Outsiders_AVC		3.039***	-0.241**	-0.405
		(0.938)	(0.101)	(0.295)
Founding_MPEG2	-0.655**	-0.357	0.087	0.087
	(0.292)	(0.410)	(0.171)	(0.375)
Founding_1394	1.142	-0.062	-0.191	0.133
	(1.088)	(0.422)	(0.178)	(0.266)
Founding_AVC	0.741	1.671***	0.125	-0.220
	(0.664)	(0.594)	(0 .141)	(0.320)
Founding_dvbt	0.106			
	(0.513)			
Founding_DVD6C	1.103***	-0.412**	0.123	0.406**
	(0.149)	(0.190)	(0.139)	(0.177)
Founding_MPEG4sys		19.440***		-0.256
		0.954		(0.418)
Founding_MPEG4vis		-0.071	-0.217	0.075
		(0.340)	(.147)	(0.242)
Age input	-0.007*	-0.011***	0.001	-0.002
	0.004	(0.004)	(0.002)	(0.003)
Patent age effect	Y	Y	Y	Y
Pool dummies	Y	Y	Y	Y
Obervations	707	1229	1164	1208
Number of clusters	141	190	162	190
Pseudolikelihood	-391.19	-4147.11	-1531.13	-4476.33

Legend: * p<0.10; ** p<0.05; *** p<0.01*. Robust standard error clustered in parentheses.*

Table 13. Regression results by pools, coefficients

Chapter III

Appendix 1

Pool	Pool Launch	License Available	Standard
mp3	1992	1992	ISO/IEC11172-3
MPEG2	1997	during 1997	ISO/IEC13818-1/ITU-TH.220.0
DAB	1998	1998	ETS300401
G.729	1998	July 1999	G.729
G723.1	2000	from 2000	G.723.1
IEEE1394	2000	2000	IEEE1394
MPEG2AAC	2000	2000	ISO 13818-7 (MPEG2 AAC)
DVB-T	2001	during 2001	EN300744
MPEGAUDIO	2001	2001	ISO/IEC11172-3
MPEG4Audio	2002	2002	ISO/IEC14496-3
MPEG4Visual	2002	2002-11-25	ISO/IEC14496-2
MPEG4Systems	2003	2003-2-4	ISO/IEC 14496.1
AMR	2004	2004-2-24	AMR
AMR-WB+	2004	2004-10-4	AMR-WB+
AVC	2004	2004-7-15	ISO/IEC14496-10/ITUH.264
DRM	2005	2005-3-28	ETSI ES 201 980 V1.2.2 (2003-4); ETSI TS 101 968 V1.1.1 (2003-04); IEC 62272-1 Ed. 1
IEEE802.11	2005	2005-4-14	IEEE802.11/ISOIEC8802-11
UHFRFID	2005	2005	ISO/IEC18000-6
DVB-MHP	2006	2006-3-2	ETSI …
MPEG2Systems	2006	2006-4-16	ISO/IEC13818-1/ITU-TH.220.0
OCAP	2006	2007-6-5	.
NFC	2007	2007-6-5	ISO/IEC18092
VC1	2007	2007-3-14	.
G729.1	2008	2009-1-12	G.729.1
AGORA-C	2009	2009-8-5	ISO 17572-3
AMR-WB/G.722.2	2009	3Q 2009	G.722.2
CDMA-2000	2009	2009-6-10	CDMA Family: CDMA2000 1X, CDMA2000 1xEV-DO and Ultra Mobile Broadband (“UMB”)
G711.1	2009	beginning 2009	G.711.1

Table 3: List of patent pools and related standards

Appendix 2

DV = patent declaration

Variable	Coef.	(Std.Err.)
3-4 y. before pool launch	1.230***	(0.290)
1-2 y. before pool launch	1.245***	(0.276)
1-2 y. after pool launch	0.598**	(0.300)
3-4 y. after pool launch	0.611**	(0.293)
5-6 y. after pool launch	0.278	(0.332)
Version Release	0.090***	(0.140)
Amendment	0.220***	(0.042)
Standard Age	0.161***	(0.008)
Standard Age Square[1]	-0.001***	(0.001)
Standard Year Dummies	Included	
Observation	8,730	
Groups	485	
Log likelihood	-5,805	

Notes: All models are estimated using the conditional fixed-effects poisson estimator, standard errors (reported in parentheses). ***, **,and * imply significance at the 99%, 95%, and 90% levels of confidence, respectively.
[1]Coefficient multiplied by 100 to make effects visible.

Table 3: Timing of patent declarations around pool creation

Appendix 3:

Standard Updates						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	567	0.360	0.057	1.361	0.248	0.472
St. with Pool	17	3.647	0.818	3.372	1.914	5.381
t = -9.1848 Pr(|T| > |t|) = 0.0000						
Number Pages						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	567	89.280	7.504	178.681	74.541	104.019
St. with Pool	17	159.882	37.181	153.301	81.061	238.703
t = -1.6111 Pr(|T| > |t|) = 0.1077						
Accompanying Standards Consortia						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	568	0.132	0.022	0.526	0.089	0.175
St. with Pool	17	1.941	0.466	1.919	0.954	2.928
t = -12.0743 Pr(|T| > |t|) = 0.0000						
Declaring Companies						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95 %ConfInterval]	
St. without Pool	568	7.273	0.652	15.527	45.99	8.553

St. with Pool	17	55.882	18.521	76.366	16.61	95.146
t = -9.9426 Pr(|T| > |t|) = 0.0000						
NPE on Standard Dummy						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	568	0.276	0.019	0.448	0.240	0.313
St. with Pool	17	0.824	0.095	0.393	0.621	1.026
t = -4.9816 Pr(|T| > |t|) = 0.0000						
NPE Share (for Standards with NPEs)						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	157	0.296	0.019	.235	.259	0.334
St. with Pool	14	0.147	0.021	.077	.102	0.191
t = 2.3571 Pr(|T| > |t|) = 0.0196						
Gini Coefficient of Essential Patent Dispersion						
Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
St. without Pool	511	0.175	0.010	0.228	0.155	0.195
St. with Pool	17	0.267	0.048	0.199	0.165	0.369
t = -1.6484 Pr(|T| > |t|) = 0.0999						

Table 4: T-Test analysis t-tests of explanatory variables by standard with and without patent pools

Appendix 4:

PSM Sampling for comparable standards

Our goal is to identify a comparable sample of standards that are licened individually to match it with partly pooled licensed standards. Propensity score matching (PSM) is a widely used approach to estimate causal treatment effects. We therefore apply a logit based propensity score matching algorithm to identify a common support region for both samples. In a first step we search for variables that explain the occurrence of pool formation. It is important to only use variables that are unaffected by the treatment (Heckman et al., 1999). We therfore only employ variables that are measured before pool formation. In particular we only estimate variables until two years after standard release to ensure a uniform measure among standards. In the literature it is argued that choosing to many variables might excaberate the support problem (Bryson et al., 2002). When including non-significant variables to explain the treatment, the propensity score estimates will not be biased but increase in their variance. As to Heckman et al. (1998) we therfore include all explanatory variables in our estimation and only keep variables when they are statistically significant and when they increase the prediction rates. Proceeding that way we dismiss standard characteristics such as the number of pages, the number of declaring companies, the number of essential patents and the gini coefficient of patent distribution. All of these variables did not significantly explain a pool formation and did not increase our prediction results. In comparison we found significant results for the occurrence of NPEs on standards, the existance of collaborating standards consortia and the number of standards updates (table 5).

DV= Pool Exists	Coef.	(SE)	Z
Standard Updates	0.099*	(0.055)	1.81
Standard Consortia	0.259**	(0.114)	2.28
NPE Share	-4.188*	(2.257)	-1.86
Constant	-0.882	(0.444)	-1.99
Observations		102	
Pseudo R		0.3038	
Log likelihood		-27.091	

Table 5 Probit Regression

As to our t-test results more than 82% of the standards where we find a patent pool have at least one NPE that has declared essential patents on that same standard. We believe this to be an objective restriction to identify a comparable sample of standards. As discussed earlier, NPEs are an indicator of licensing profits from essential patents. Our PSM estimation is thus restricted to standards where at least one NPE declares essential patents and where the release of the standard has at least been three years ago. Table 5 shows that standards with consortia, with more updates but a lower NPE share explain the formation of pools. The latter result indicates that the occurrence of NPEs is positivley connected while a higher share is negativly connected. Our former conducted t-test proved these results.

Figure 3 shows results of our PSM graph of treated (strandards with pools) and untreated (individually licensed standards) goups. We apply the nearest neighbor matching method where we identify matching partners of treated and untreated standards. We use a matching with replacement, where we allow matching an untreated standard observation more than once. This method is especially efficient when we have very different propensity scores as evidence in figure 10. Matching high with low values would result in bad matches. We overcome this problem by allowing replacement which on the other hand increases the variance of the estimator (Smith and Todd, 2005).

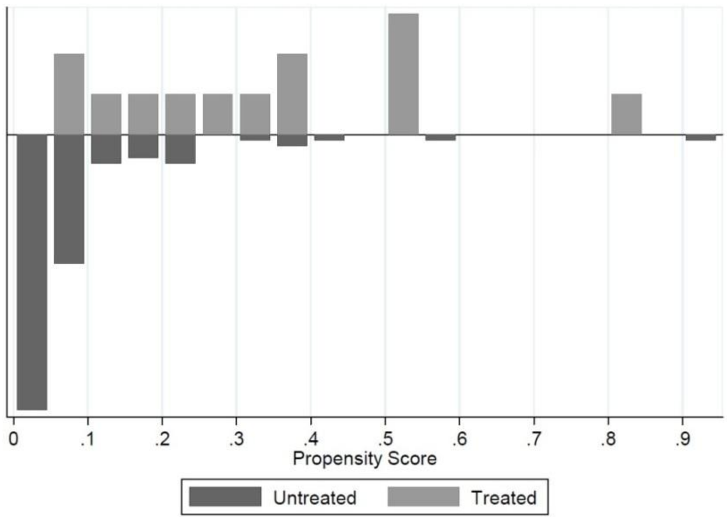

Figure 10 psm matching results

We also apply a maximum propensity score distance (caliper) but our neighbor matches remain the same. We conduct a sample statistic test after our propensity score matching. Table 6 shows that there are no remaining significant differences between characteristics of the standards in the two samples.

		Mean		% bias	% reduct	t-test	
Variable	Sample	Treated	Control		bias	T	p>t
Standard	Unmatched	4.384	1.303	101		3.68	0.000
Updates	Matched	4.384	7.230	-93.3	7.6	-1.59	0.124
Standard	Unmatched	2.231	0.404	113.5		5.03	0.000
Consortia	Matched	2.231	1.231	62.1	45.2	1.23	0.230
NPE	Unmatched	0.139	0.271	-85.3		-2.28	0.025
Share	Matched	0.139	0.127	7.4	91.4	0.47	0.642

Table 6 Sample statistics, matched and unmatched samples

Appendix 5:

Time shift analysis

DV= patent files	M5	M5-1	M5-2
Variable	Coef. (S.E.)	Coef. (S.E.)	Coef. (S.E.)
standard age before 2002	-0.009***	0.004*	0.005**
	(0.001)	(0.002)	(0.002)
standard age * pool exists before 2002	-0.001***	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
standard age after 2002	-0.006***	-0.006***	-0.005***
	(0.001)	(0.001)	(0.001)
standard age* pool exists after 2002	-0.004***	-0.003*	-0.003*
	(0.001)	(0.002)	(0.002)
patent files in G and H 1	0.011***	0.002	0.001
	(0.001)	(0.001)	(0.001)
Lag 1 standard Upgrade	-0.016	-0.006	-0.002
	(0.01)	(0.008)	(0.005)
Lag1 patent Files	0.001**	0.002***	0.001***
	(0.001)	(0.001)	(0.001)
Standard Year Dummies	Included	Included	Included
Added Restriction standard time and years	No restrictions	4 years bef. & aft. standard release	M5 restriction + 1995-2005
Observation	10,228	4,232	3,259
Groups	640	640	466
Log likelihood	-9,044,428	-2,107,350	-1,688,240

Note: All models are estimated using the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗, ∗∗,and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible.

Table 7 Shift in the patenting timing with respect to standard development

Chapter IV

Appendix 1:

Variable	Description	Level of Obs.	Obs	Mean	Std. Dev.	Min	Max
Standard Specific R&D	Triadic Patent Priority Filings by this firm in the standard-related IPC classes	Firm-Standard-Year	31,020	1,072	4,022	0	91,121
Member	Membership of this Company in the Consortium related to this standard	Firm-Standard-Year	39,816	0.058	0.234	0	1
Over Investment	The share of non-producing entities for this standard	Standard	31,312	0.120	0.138	0	1
Standard Event	Sum of Amendments and version Releases	Standard-Year	36,918	0.292	0.979	1	37
ICT Patent Files	Triadic patent priority filings by all firms in either Telecom or IT	Standard-Year	37,621	223,320	52,748	132,721	301,890
Patent Declarations	Number of patent declarations to all formal standards	Year	39,834	3,538	4,038	78	13,938
Tobin's Q	Market-to-book ratio of the firm	Firm-Year	11,740	1.702	1.598	0.076	8.257
Sales	Value of sales per year in Million USD	Firm-Year	17,780	35,694	30,172	895	199,925

Table 5: Overview over the relevant variables

Appendix 2:

Consortia Name	MatchStandard	Incl	Consortia Name	MatchStandard	Incl	Consortia Name	MatchStandard	Incl
EPCglobal	EN300220	No	WiMax	IEEE802.16	Yes	MPEGIF	ISO/IEC14496-14	Yes
DVB	EN300468	No	Cable Laboratories	IEEE802.1Q	Yes	MPEGIF	ISO/IEC14496-15	Yes
DVB	EN301192	No	FCIA - Fibre Channel Industry Association	IEEE802.1Q	No	MPEGIF	ISO/IEC14496-16	No
DVB	EN301199	Yes	MEF	IEEE802.1X	No	MPEGIF	ISO/IEC14496-18	Yes
DVB	EN301790	No	IETF	IEEE802.21	Yes	MPEGIF	ISO/IEC14496-19	No
DVB	EN301958	Yes	(GEA	IEEE802.3	No	ISMA	ISO/IEC14496-2	Yes
EPCglobal	EN302208	No	AUTOSAR	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-2	No
DVB	EN302304	No	FCIA	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-20	No
DVB	EN302307	No	HGI	IEEE802.3/ISOIEC8802-3	No	ISMA	ISO/IEC14496-3	Yes
DVB	EN302583	No	IETF	IEEE802.3/ISOIEC8802-3	Yes	MPEGIF	ISO/IEC14496-3	Yes
DVB	EN302755	No	MEF	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-4	Yes
DVB	ES200800	Yes	ODVA	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-5	Yes
IETF	ES201108	Yes	OIF	IEEE802.3/ISOIEC8802-3	No	MPEGIF	ISO/IEC14496-6	Yes
IETF	ES202050	Yes	Rapidio	IEEE802.3/ISOIEC8802-3	No	TAHI	ISO/IEC14543-2-1	No
IETF	ES202212	Yes	IETF	IEEE802.5/ISOIEC8802-5	No	IETF	ISO/IEC15444-1	No
WORLDDAB FORUM	ETS300401	Yes	INCITS	ISO/IEC10118-2	No	IETF	ISO/IEC15444-12	No
DVB	ETS300814	Yes	INCITS	ISO/IEC10118-3	Yes	IETF	ISO/IEC15444-2	No
DVD	ETSIEN300468	No	INCITS	ISO/IEC10536-3	No	IETF	ISO/IEC15444-3	Yes
IETF	G.711	Yes	INCITS	ISO/IEC10918-1/ITU-TT.81	Yes	IETF	ISO/IEC15444-5	No
IETF	G.722	Yes	TOG	ISO/IEC10918-1/ITU-TT.81	No	EPCglobal	ISO/IEC15693-2	No
IETF	H.263	Yes	INCITS	ISO/IEC11172-1	No	EPCglobal	ISO/IEC15693-3	No
IMTC	H.323	Yes	DVD	ISO/IEC11172-2	No	EPCglobal	ISO/IEC18000-1	No
IMTC	H.324	No	INCITS	ISO/IEC11172-2	No	EPCglobal	ISO/IEC18000-2	No
IETF	IEC6183411	No	DVD	ISO/IEC11172-3	No	EPCglobal	ISO/IEC18000-3	No
TOG	IEEE1003.1/ISOIEC9945	Yes	INCITS	ISO/IEC11172-3	Yes	EPCglobal	ISO/IEC18000-4	No
PICMG	IEEE1101.1	Yes	INCITS	ISO/IEC11693	No	EPCglobal	ISO/IEC18000-6	Yes
OCP-IP	IEEE1149.1	Yes	INCITS	ISO/IEC11694-1	No	AIM	ISO/IEC18000-6	No
BPMI	IEEE1226.5	No	INCITS	ISO/IEC11770-3	No	AIM	ISO/IEC18000-7	No
OMG	IEEE1226.5	No	INCITS	ISO/IEC11889-1	Yes	EPCglobal	ISO/IEC18000-7	Yes
PWG	IEEE1284	Yes	INCITS	ISO/IEC11889-2	Yes	ECMA	ISO/IEC18092	No
1355 Association	IEEE1355	No	INCITS	ISO/IEC11889-3	Yes	EUROSMART	ISO/IEC18092	No
1394TA	IEEE1394	Yes	INCITS	ISO/IEC11889-4	Yes	NFC Forum	ISO/IEC18092	Yes
AUTOSAR	IEEE1394	No	DMPF	ISO/IEC13818-1/ITU-TH.220.0	No	INCITS	ISO/IEC19794-3	No

DVD	IEEE1394	No	DVD	ISO/IEC13818-1/ITU-TH.220.0	No	INCITS	ISO/IEC19794-6	Yes
HAVi	IEEE1394	No	INCITS	ISO/IEC13818-1/ITU-TH.220.0	Yes	ECMA	ISO/IEC23651	No
PWG	IEEE1394	No	DVD	ISO/IEC13818-2/ITU-TH.262	No	GS1 – (Formerly EAN)	ISO/IEC24730-2	No
ODVA	IEEE1588/IEC61588	Yes	INCITS	ISO/IEC13818-2/ITU-TH.262	Yes	ECMA	ISO/IEC28361	No
ACCELLERA	IEEE1800/IEC62530	No	TOG	ISO/IEC13818-2/ITU-TH.262	No	TAHI	ISO/IECDIS29341	No
ACCELLERA	IEEE1801	Yes	DVD	ISO/IEC13818-3	No	UPnP Forum	ISO/IECDIS29341	Yes
Homeplug	IEEE1901	No	INCITS	ISO/IEC13818-3	Yes	ECMA	ISO/IECDIS29500	No
IVI	IEEE488.1/IEC60488-1	No	INCITS	ISO/IEC13818-7	No	3GPP2	Q.703	No
ASTM	IEEE802.11/ISOIEC8802-11	No	EUROSMART	ISO/IEC14443-1	No	DVB	TS102474	No
Bluetooth	IEEE802.11/ISOIEC8802-11	No	INCITS	ISO/IEC14443-1	No	DECT Forum	TS102527	No
DLNA	IEEE802.11/ISOIEC8802-11	No	NFC Forum	ISO/IEC14443-1	No	DVB	TS102584	No
ewc	IEEE802.11/ISOIEC8802-11	No	EUROSMART	ISO/IEC14443-2	No	DVB	TS102611	No
HGI	IEEE802.11/ISOIEC8802-11	No	INCITS	ISO/IEC14443-2	Yes	TV Anytime Forum	TS102822	No
IETF	IEEE802.11/ISOIEC8802-11	No	NFC Forum	ISO/IEC14443-2	No	DVB	TS102825	No
Wi-Fi Alliance	IEEE802.11/ISOIEC8802-11	Yes	EUROSMART	ISO/IEC14443-3	No	IMS FORUM	TS123002	No
100VG-Anylan Forum	IEEE802.12	No	INCITS	ISO/IEC14443-3	Yes	3GPP2	TS123401	No
IETF	IEEE802.12/ISOIEC8802-12	No	NFC Forum	ISO/IEC14443-3	No	3GPP2	TS123402	No
Bluetooth	IEEE802.15.1	No	EUROSMART	ISO/IEC14443-4	No	3GPP2	TS133402	No
WiMedia Alliance	IEEE802.15.3	Yes	INCITS	ISO/IEC14443-4	Yes	DRM	TS201980	No
DISA	IEEE802.15.4	No	NFC Forum	ISO/IEC14443-4	No	IETF	V.44	No
IETF	IEEE802.15.4	No	ISMA	ISO/IEC14496-1	Yes	3GPP2	X.509	No
TAHI	IEEE802.15.4	No	MPEGIF	ISO/IEC14496-1	No	ASTM	X.509	No
ZigBee	IEEE802.15.4	No	ISMA	ISO/IEC14496-10	Yes	Cable Laboratories	X.509	Yes
IETF	IEEE802.16	No	MPEGIF	ISO/IEC14496-10	No	ISMA	ISO/IEC14496-10/ITUH.264	Yes
			MPEGIF	ISO/IEC14496-12	Yes			

Table 6: Linkages between standards and informal consortia

Appendix 3:

Methodology for measuring standard-related R&D

We identify the precise relevant technological field for each standard by using the 7-digit IPC[103] classification of the declared essential patents, and then count the patents filed by each company and by year in the identified IPC classes. We used all ICT patents filed from 1992 to 2009 by the companies in our sample at the three major patent offices (USPTO, JPO and EPO), using the PatStat database and the merging methods of Thoma et al. (2010). This merging yields 13 million patent files. We aggregated these patents to INPADOC patent families and informed the IPC classification and the year of priority. To create our explained variable, we computed for each company-standard pair and year the number of patents filed in the relevant IPC classes for the standard of observation.

This method is a novel way of measuring standard-specific R&D investment, and we therefore conduct a reliability analysis. We compute for each company-standard pair the mean number of patents filed in one year periods before and after standard release (t=0) and report the standard derivation for high and low values (figure1). The resulting pattern is a realistic description of the innovation process around standardization: the number of patents filed is highest in the years immediately preceding standard release, and sharply decreases after release of the standard. The further we move away from the development phase of the standard, the lower are the calculated numbers of relevant patents. We believe that these findings are important arguments corroborating our methodology.

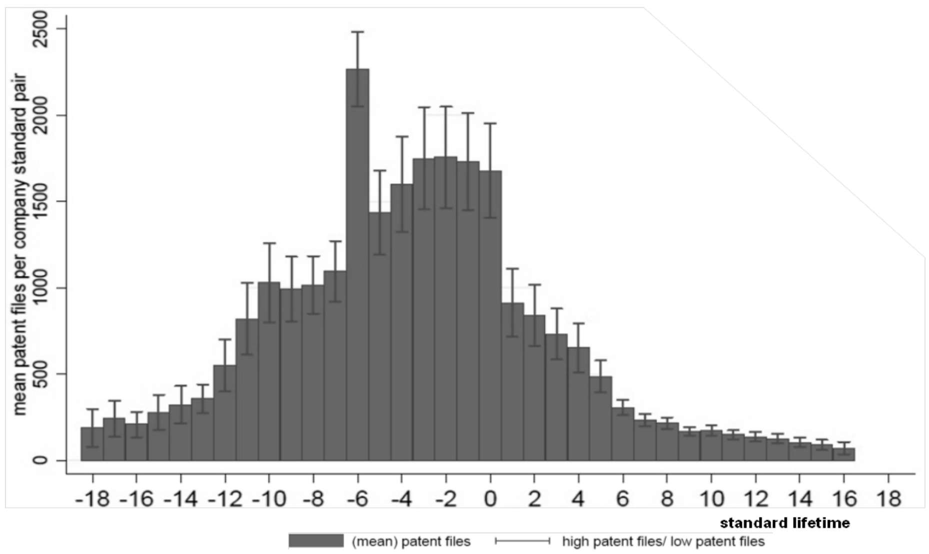

Figure1: mean number of patents filed in years before and after standard release

[103] International Patent Classification

Appendix 4:

Empirical Methodology for sorting standards into cases of over- and underinvestment

Based upon the theoretical model, we use the participation of pure R&D firms to indicate overinvestment in a standard. We observe participation of pure R&D firms in a standard using our database of companies declaring patents. Only firms that declare patents on a respective standard are considered as participants. Firms are classified as pure R&D firms using the business description database of Thomson One Banker and the companies identified by Layne-Farrar and Lerner (2011).

Using this classification, we plot the standards with over- or underinvestment in a graph. The axes of the scatter plots are the residuals of two regressions of the number of patent declarations and the number of filed patents in the field on observable characteristics of the standard and the firm. We assume negative residuals to be an indicator of underinvestment, whereas positive residuals indicate over-investment. Regarding patent files, our first labeling of over- and underinvestment apparently proves to be a sufficient classification, since all residual values of the patent file regression are positive (positive X values). The identification of underinvestment seems to be less satisfactory. Residuals of patent declarations however display ambiguous results. We interpret these results as indicating that declarations are a noisy measure of standard specific R&D investment (see Chapter 3 for a comparison of patent and declaration counts).

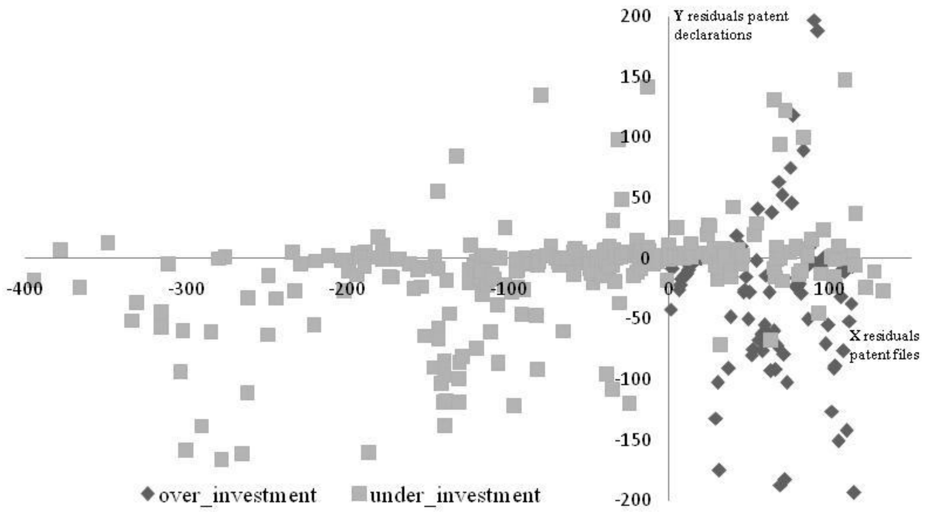

Figure 2: Scatter plot of residual values labeled with over- and underinvestment

These results confirm our hypothesis that pure R&D firms indicate overinvestment. In order to refine the measurement; we calculate for each standard the share of pure R&D firms compared to other firms contributing to the standard. This is the share which we use as indicator of overinvestment in this article.

Appendix 5:

Robustness check substituting pre-sample means for fixed effects

We apply the methodology developed by Blundell et al. (1999) to control for predetermined regressors. The authors suggest substituting the pre-sample averages of the dependent variable for the group fixed effect. While the fixed effects are estimated over the sample period, and thus affected by the feedback of predetermined regressors, the pre-sample means are exogenous to the sample period values of the regressors. Analogous to our previous analysis, we set the period of observation from 2002 to 2009. In choosing the appropriate pre-sample period, we have to trade off endogeneity (several consortia memberships observed in the sample period have already existed in the period from 1992 to 2001) against heterogeneity (closer pre-sample values are a better approximation of the sample fixed effect than more remote pre sample information). As this model is intended to complement a fixed effect analysis, we choose the average of the period from 1982 to 1992 as pre-sample values[104]. We control for the same variables and operate the same sample restrictions as in the main model. As our dependent variable is over-dispersed with respect to a poisson distribution and we no longer include group fixed effects, we now opt for a negative binomial regression. The results are displayed in table 5. The coefficients of the consortia membership variables are similar to those in the poisson fixed analysis, but the interaction term of consortia membership and overinvestment is no longer significant.

104 Additionally including the closer pre-sample information (1992 to 2002) does not alter significantly the reported results.

	Unit of Observation = Year DV = Standard Specific R&D Investment (Patent Files)			
	M11		M12	
	Coef.		Coef.	
Member	0.147 (0.043)	***	0.224 (0.075)	***
Member * Over Investment	-1.163 (0.905)	***	-1.783 (1.113)	***
Lag1 Patent Files[1]	0.033 (0.003)		0.033 (0.003)	
ICT Patent Files[1]	0.009 (0.001)		0.009 (0.001)	
Patent Declarations[1]	0.015 (0.003)		0.015 (0.003)	
Lag1 Sales[1]	-0.008 (0.001)		-0.008 (0.001)	
Pre Sample Means (1982-1992)	0.001 (0)	**	0.001 (0)	**
Standard Dummies	Included		Included	
Log Likelihood	-19,564		-19,569	
AIC	39,261		39,270	
BIC	39,646		39,656	
Observations	2,550		2,550	
Groups	349		349	

Notes: All models estimated with the conditional fixed-effects poisson estimator with robust clustered standard errors (reported in parentheses). Standard errors are robust to arbitrary heteroskedacity and allow for serial correlation through clustering by firm. ∗∗∗, ∗∗, and ∗ imply significance at the 99%, 95%, and 90% levels of confidence, respectively. [1]Coefficient multiplied by 1,000 to make effects visible.

Table 5: Robustness analysis with mean scaling and negative binominal estimation

Chapter V

Appendix 1

Patented_dummy	Indicates that a standard observation includes essential patents	Time invariant
Patented	Indicates a standard has received at least one patent declaration by this year	Time-variant
Patented_upgrade	Interaction term between patented and event-type upgrade	Time invariant
Patented_replacement	Interaction term between patented and event-type replacement	Time invariant
Patents_cumulative	Cumulative count of patents declared over time	Time-variant
Innovation intensity	Number of patents filed per year in the technological field, normalized by year; indicates strong innovative activity	Time-variant
Technology gap	Cumulative count of patent intensity scores since standard release, discount factor 15%; indicates distance of the standard to the technological frontier	Time-variant
Backward references	Number of standards referenced by the standard	Time-invariant*
Change of referenced	Counts the number of referenced standards that are replaced or upgraded per year	Time-variant
Forward references	Cumulative count of the references made to the standard by ulterior standards in the PERINORM database	Time-variant
Referencesafter4	Number of references received during the first four years after first standard release	Time invariant
atleastonereference	Referencesafter4 is bigger than 0	Time invariant
Ulterior accreditations	Cumulative count of the number of accreditations by other SDOs after release of the standard at the sample SDO	Time-variant
Prior accreditations	Count of the accreditations by other SDOs before the release of the standard at the sample SDO	Time-invariant*
National Standard	Indicates that the standard was not first developed at the sample SDO (Prior accreditations is higher than 0)	Time-invariant*
Number of pages	The number of pages of the standard	Time-invariant*
ICS width	The number of ICS classes in which the standard is classified	Time-invariant*
Year	Calendar Year	Time-variant
*	Number pages, backward references, ICS width and prior accreditations can change with a new version	

Table 4: Definition of variables

Appendix 2

Calculation of the propensity score

Probit regression				Number of observations:	6531	
				LR chi2(55):	646,62	
				Prob >chi2:	0,0000	
Log Likelihood:	-992,116			Pseudo R2:	0,2458	
Variable	Coef.	Std. Error	Z	Pr>|z|	95% Confidence Interval	
number_pages	0,00257	0.00030	8,46	0,000	0,0019	0,0032
at_least_one_reference	0,27398	0.07319	3,74	0,000	0.1305	0.4174
references_after_4years	0.00406	0.00321	1,26	0,206	-0.0022	0,0103
Nationalstandard	-0.57748	0,26795	-2.16	0.031	-1.1027	-0.0523
prior_accreditations	0.41569	0,18716	2.22	0.026	0.0489	0.7825
ics_width	0.26732	0,20240	1,32	0,187	-0.1294	0.6640
It	-0.15721	0.21168	-0.74	0.458	-0.5721	0.2576
Telecom	0.64812	0,19895	3.26	0.001	0,2581	1.0381
Ieee	1.64179	0,38053	4.31	0.000	0.8959	2.3876
Iso	0,92272	0,40467	2.28	0.023	0.1296	1.7159
jtc1	1.30466	0.37165	3.51	0.000	0.5762	2.0331
itu-t	1.83084	0.35116	5.21	0.000	1.1426	2.5191
Constant	-3.80847	0.51554	-7.39	0.000	-4.8189	-2.7980
Year dummies and ICS-class dummies not reported						
There are observations with identical propensity scores.						

Table 5: Probit regression model used for calculating the propensity scores

Pstrata	patented_dummy		Total
	0	1	
1	734	7	741
2	730	11	741
3	719	21	740
4	707	34	741
5	662	78	740
6	562	180	742
Total	4.114	331	4.445

Table 6: Standards with and without essential patents, by strata

Appendix 3

Sensitivity analysis to unobserved biases using multiple control groups

SDO	Number of Standards in ICT from 1988 to 2008	% of these standards including patents	Classified as SDO with patents
ISO	1169	2,10 %	No
IEC	1348	0,59 %	No
JTC1	1704	5,81 %	Yes
ITU-T	3874	6,43 %	Yes
ITU-R	1217	0,41 %	No
IEEE	477	8,59 %	Yes

Table 7: SDOs classified as with or without patents

ICS "with" patents			ICS "without" patents		
ICS	Standards	% patents	ICS	Standards	% patents
33040	1792	6,25	33020	659	0,30
33160	589	10,88	33030	62	0,00
35040	473	17,55	33050	138	2,89
35110	409	11,25	33060	970	0,93
35180	98	10,20	33070	53	0,00
Others	65	25,76	33080	510	4,90
			33100	193	0,00
			33120	234	0,00
			33140	19	5,20
			33170	516	2,52
			33200	51	1,96
			35020	57	0,00
			35060	229	2,18
			35080	257	0,80
			35140	74	2,70
			35160	97	3,10
			35200	309	5,82
			35240	1606	4,73
			37040	16	0,00
			37060	21	0,00
			Others	1419	0,85

Table 8: ICS classes classified as with or without patents

Standard replacement		Test without strata	Test without strata, controls	Test with strata	Test with strata, controls
	Events				
Treated	Obs: *Exp:*	20 *49,46*		20 *54.91*	
Control 1	Obs: *Exp:*	50 *56,88*	50 *58,74*	50 *59.37*	50 *61,11*
Control 2	Obs: *Exp:*	674 *549,00*	674 *565,65*	674 *626.80*	674 *652,41*
Control 3	Obs: *Exp:*	270 *358,66*	270 *369,61*	270 *272.93*	270 *280,48*
Chi2 Pr>chi2		69,29 0,0000	49.16 0,0000	30.16 0,0000	3,91 0,1419

Table 9: Log rank test of equality of standard survival with multiple control groups

Standard upgrade		Test without strata	Test without strata, controls	Test without strata, 2 controls	Test with strata	Test with strata, controls	Test with strata, 2 controls
	Events						
Treated	Obs: *Exp:*	267 153,69			267 171,03		
Control 1	Obs: *Exp:*	41 94,77	41 89,35		41 88,78	41 81,43	
Control 2	Obs: *Exp:*	1064 992,61	1064 936,02	1064 960,53	1064 1064,75	1064 1023,19	1064 1045,69
Control 3	Obs: *Exp:*	838 972,93	838 917,63	838 941,47	838 889,44	838 838,38	838 856,31
Chi2 Pr>chi2		146,29 0,0000	53,07 0,0000	23,67 0,0000	101,77 0,0000	27,82 0,0000	1,09 0,2962

Table 10: Log rank test of equality of version survival with multiple control groups

Innovation et coordination dans les standards NTIC - le rôle des brevets essentiels

RESUME : Cette thèse étudie le rôle des brevets essentiels pour la coordination de l'innovation dans les standards des Nouvelles Technologies d'Information et de Communication (NTIC). Les firmes actives dans la standardisation ont réagi au défi de la marée de brevets essentiels en créant des mécanismes innovateurs de coordination, et notamment des consortia informels de standardisation et des pools de brevets. La thèse met en lumière le mécanisme d'appropriation original que représentent les brevets essentiels. Ce mécanisme peut cependant générer des incitations à recourir à des stratégies opportunistes. Les pools de brevets peuvent exacerber ces incitations, mais induisent également une augmentation du nombre de brevets déposés autour des standards technologiques. Les consortia informels ont un effet positif sur le nombre de brevets liés aux standards si les incitations à innover sont insuffisantes. L'effet des consortia est plus faible, voire négatif, si les incitations à innover sont excessives. Les brevets essentiels influencent le progrès technologique des standards, notamment en donnant lieu à un progrès plus continu, consistant dans de nombreuses mises à jour et évitant les remplacements de standards.

Mots clés : Standards technologiques, brevets essentiels, pools de brevets, consortia

Innovation and Coordination for ICT Standards - the Role of Essential Patents

ABSTRACT : This thesis studies the role of essential patents for the coordination of innovation in ICT standards. The increasing number of essential patents around technological standards is an increasing challenge for standardizing firms. In response, these firms have developed innovative coordination mechanisms, and in particular patent pools and informal standards consortia. This thesis sheds light on the function of essential patents as a distinctive appropriation mechanism tailored to cumulative innovation. This mechanism can however induce incentives for opportunistic strategies, which can be even exacerbated by patent pools. Nevertheless, patent pools also lead to an increase in the number of patented technologies developed for technological standards. Informal consortia induce an increase in the number of standard-related patents when incentives to innovate are insufficient. When the incentives to innovate are excessive, the effect of consortia on the number of patents is weaker, or even negative. Essential patents have an incidence on the technological progress of standards. For instance, inclusion of essential patents induces a more continuous type of technological progress, consisting in many small standard updates, and avoiding discontinuous standard replacements.

Keywords : Technological standards, essential patents, patent pools, consortia